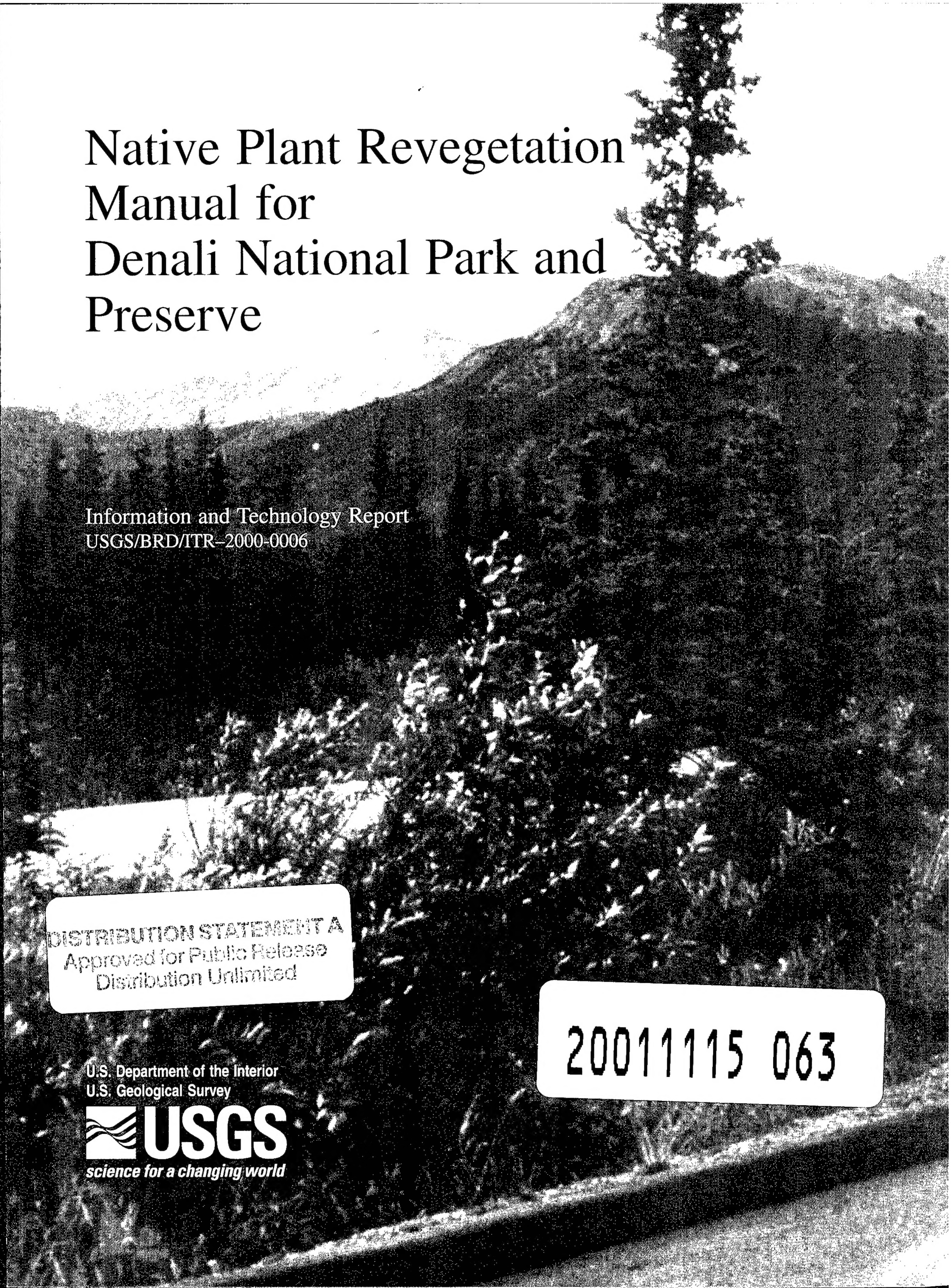
Native Plant Revegetation Manual for Denali National Park and Preserve



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Abstract: This manual describes methods to revegetate subarctic sites with native plants. The information is based on 20 years of research and revegetation projects in Denali National Park and Preserve and other Alaskan sites. The manual summarizes information about subarctic ecosystems and discusses using this information to evaluate disturbed sites and plan revegetation projects. Revegetation techniques addressed include promoting natural revegetation, legume and wheatgrass seeding, plant salvage and transplant, bioengineering, container-grown plants, alder seedlings, and willow cuttings. Long-term data for two specific vegetation projects and for each of the 46 native plant species that have been tested or used for revegetation are presented.

Key words: revegetation, restoration ecology, native plants, bioengineering, habitat restoration, Denali National Park, Alaska

Introduction

Denali National Park and Preserve (DNPP) covers 2.4 million ha in interior Alaska. In the past, the land was used by native peoples, miners, settlers, and hunters (Brown 1993), and today, DNPP is toured by hundreds of thousands of visitors each summer. Plant communities in the park have been damaged or destroyed by human activities such as trampling, construction of roads and visitor facilities, and past mining.

The rate of natural revegetation on disturbed sites is slow, particularly on well-drained areas without topsoil. Some road cut slopes and placer mine tailings have little or no vegetation 30 to 50 years after disturbance. Plant growth in the subarctic environments of DNPP is limited by the interrelated effects of a short growing season, low growing season soil and air temperatures, low precipitation, and a low level of available nutrients. Growth of most species is especially slow during the establishment phase, which may take several years (Billings 1974). During this period many seedlings succumb to environmental stress such as frost action.

Assisted revegetation is needed on many areas of the park that have been disturbed to control erosion, improve visual quality, and restore ecosystem functions. National Park Service policy emphasizes minimum interference with natural ecosystem processes and the resulting plant communities, and restricts the introduction of plant material from sources outside the national parks; therefore, during the last 20 years we have studied the restoration of degraded ecosystems in DNPP and have developed many revegetation techniques which use native plant materials.

Although much of this work has been published elsewhere (Glass 1988; Densmore et al. 1990; Densmore 1992, 1994, 1997; Karle and Densmore 1994a,b; Karle et al. 1996; Densmore and Karle 1999), no single document assembles this information in a format for use in the field. In addition, many techniques and observations are not recorded anywhere, except in memories and

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field notes. This report attempts to fill that gap by compiling and synthesizing our knowledge of native plant revegetation techniques. Much of this manual was originally compiled and organized as a master's thesis by Mark E. Vander Meer (see Vander Meer 1995).

We hope this manual will (1) provide useful information for revegetation projects in Denali National Park and Preserve and (2) provide information that is applicable to other subarctic National Park Service units in Alaska and to the North American subarctic in general.

The Ecological Setting

Climate

Denali National Park and Preserve (DNPP) is located within the continental climatic zone of interior Alaska, which is characterized by seasonal temperature extremes driven chiefly by continental cooling influences and large variations in solar radiation. This area has short, warm summers and long, extremely cold winters. In DNPP, the continental pattern is modified by the higher elevations, resulting in cooler summers and higher precipitation. July, the warmest month, averages 12 °C, while January, the coldest month, averages -18 °C.

Most of DNPP is on the north side of the Alaska Range. Precipitation averages 48 cm annually, with 72% occurring from June through September. Snow accumulation ranges from 50 to 150 cm. The snowpack generally lasts from October to May. Though DNPP receives a relatively modest amount of annual precipitation, it rains on about 50% of summer days. Light snow and freezing rains can also occur in the summer. Periods of warm, dry weather extending for 1 week or more are most likely to occur in June and early July. Soil temperatures are generally cold, and many areas are underlain by continuously frozen ground (permafrost).

Plant Communities

Denali National Park and Preserve supports approximately 450 species of vascular plants. In this report, plant nomenclature follows Hultén (1968), as this reference is the easiest to obtain and use. The scientific nomenclature for some plants has changed since Hultén (1968) was published; for those plants, we list the nomenclature from the U.S. Department of Agriculture's Integrated Taxonomic Information System (ITIS; see http://www.itis.usda.gov) after the first use of the scientific name from Hultén (1968) (e.g., *Alnus crispa* [= *Alnus viridis* ssp. *crispa*]). If Hultén (1968) lists a common name which is widely used, we use the common name followed by the scientific name the first time we refer to the plant. Thereafter, we use the common name. For plants without a widely used common name, we use the scientific name throughout.

For the purposes of this report, we provide a brief description of DNPP vegetation types based on Viereck et al. (1992): boreal forest or taiga is dominated by closed (60-100% tree cover), open (25-59% tree cover), or woodland (10-24% cover) forests of white (*Picea glauca*) and black (*P. mariana*) spruce; paper birch (*Betula papyrifera*), quaking aspen (*Populus tremuloides*), and balsam poplar (*P. balsamifera*) occur in open and closed deciduous forests and in mixed forests with spruce. These forests commonly have a moss and low shrub (0.2-1.5 m) understory. Common low shrubs include lingonberry (*Vaccinium vitis-idaea*), alpine blueberry (*V. uliginosum*), crowberry (*Empetrum nigrum*), labrador tea (*Ledum palustre*), and rose (*Rosa acicularis*).

Tree line in DNPP is at about 600 m, but can extend to 850 m on protected slopes and valleys, and is most often characterized by woodland white spruce forest with shrubs, primarily dwarf birch (*Betula nana*). Riparian vegetation (e.g., on floodplains of rivers and streams) in DNPP is similar over an elevational range from boreal forest to tundra and is typified by low and tall shrubs, including willows (*Salix* sp.) and alders (*Alnus* sp.). The dominant riparian willow is Alaska willow (*S. alaxensis*), which we will refer to as feltleaf willow because this common name is more widely used than the common name listed by Hultén and is a good description of the plant's leaves. The most abundant alder species is mountain alder (*Alnus crispa* [= *Alnus viridis* ssp. *crispa*]), which we will refer to simply as alder.

Common tundra plant communities include those dominated by ericaceous shrubs, including alpine blueberry, lingonberry, crowberry, bearberry (*Arctostaphylos alpina* and *A. rubra*), *Cassiope tetragona*, and labrador tea; those dominated by dryas (*Dryas octopetala* and *D. integrifolia*); and those dominated by dwarf birch.

Subarctic Plant Ecology

This section briefly discusses aspects of subarctic plant ecology which are important to revegetation. For further information, we recommend consulting Billings (1974), Chabot and Mooney (1985), Van Cleve et al. (1986), Barbour and Billings (1988), and Shugart et al. (1992).

Reproduction and Growth

Seed Germination. Most subarctic plants disperse seed at the end of the growing season in August and September. The major exceptions are most willows, quaking aspen, and balsam poplar, which disperse seeds

in May and June. Seed dormancy patterns for the species we use in revegetation can be grouped into four types:

1. Nondormant seeds. Nondormant seeds can germinate over a wide range of temperatures as soon as they are dispersed.
2. Conditionally dormant seeds. Most species in the subarctic have seeds that are dormant under certain conditions. These seeds can germinate at high temperatures in the light but not at the lower soil temperatures which occur when the seeds are dispersed at the end of the growing season. Physiological changes occur in the seed as it overwinters, and the seeds germinate at low soil temperatures in the spring. Many species have seeds which will not germinate without light, even in the spring.
3. Deep dormant. Some subarctic plants have seeds which are completely dormant when they are dispersed. These seeds will not germinate at any temperature until they have overwintered.
4. Hardseeded. Some of the legumes, including *Oxytropis* sp., are hardseeded, that is, they have seed coats which keep water out of the seed. This seed coat must be broken or decompose before the seed can germinate.

Additional information on the germination requirements of subarctic species is presented in Densmore (1974, 1979, 1997) and Densmore and Zasada (1977, 1983), and these papers and other literature on germination of subarctic species are summarized in Baskin and Baskin (1998).

Seedling Establishment. Subarctic plants generally have smaller and lighter seeds than temperate plants. Most seeds are in the weight range of 0.3-0.15 mg per seed. This means that newly germinated seedlings are very small and do not have reserves to rapidly produce roots. For this reason, most plants require mineral soil for seedling establishment. Mineral soil is moister and cooler than the soil organic layer, which dries out quickly and can heat to 50 °C in the sun. Thus, the following should be taken into consideration during revegetation:

- Native plant seeds that are dispersed onto mulches and erosion control mats usually do not produce established seedlings.
- When topsoil is salvaged and respread, at least part of the surface of the respread soil should be firm mineral soil. The salvaged organic layer does not make a suitable seedbed.

Seedling Growth Rate. Almost all subarctic plants are perennials with seedlings that grow very slowly. Even relatively fast-growing herbs which colonize disturbed areas, such as fireweed (*Epilobium angustifolium*), do not reach mature size until the second or third year of growth. Colonizing trees and shrubs such as alder, quaking aspen, paper birch, and willow usually grow quite slowly for several years, then grow more rapidly to mature size. Species which dominate the later stages of succession, such as spruce, dwarf birch, alpine blueberry, and labrador tea, remain small and relatively inconspicuous for about 10 years and continue to grow relatively slowly throughout life. This is partly because subarctic plants have high root to shoot ratios (see Root to Shoot section), and most of the early growth goes into the root system. The following should be taken into consideration during revegetation:

- Natural revegetation from seed or assisted revegetation with direct seeding of native plants will not provide surface erosion control for 1 to 10 years.
- Revegetation from seed will not improve visual quality for 1 to 10 years.
- Seedlings are too small during their first year to use much fertilizer. Standard rapid-release fertilizers applied at the time of seeding usually leach out of the soil before the plants are large enough to utilize the fertilizer.

Root to Shoot Ratio. Subarctic plants, particularly tundra plants, have a high root to shoot ratio. This means the biomass of roots is much larger (sometimes as much as six times larger) than the aboveground biomass of stems and leaves. The large root mass is needed to obtain nutrients and water at low soil temperatures. Consider the following:

- Plants which are fertilized in the greenhouse or in the field with rapid-release fertilizer will tend to develop a low root to shoot ratio. Once the fertilizer is gone, aboveground growth will stagnate for a long period of time while the plants expand the root system.
- Container-grown plants should have less fertilizer (especially nitrogen) than is usually applied to horticultural plants or top growth will be stimulated at the expense of roots.
- Slow-release fertilizer should be used in all field seeding and transplanting.

Shape of the Root System. Subarctic plants have shallow root systems which spread horizontally, with most of the roots occurring in the top 40-50 cm of the soil (Fig. 1). This is primarily because soil temperatures are too low or the soil is frozen at lower depths. Because of these shallow root systems, the following should be considered:

- Standard transplanting methods for trees and shrubs need to be modified to accommodate a root "saucer" instead of a root "ball." Tree spades are impractical because of the spreading root systems and rocky soils.

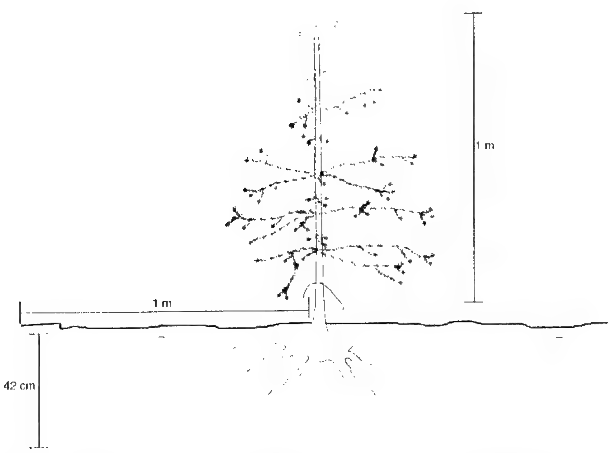

Fig. 1. Diagram of a 1-m tall spruce tree showing the spreading, shallow root system.

- When salvaging topsoil and/or vegetation, only the shallow rooting zone needs to be salvaged, and the salvaged vegetation should be in large blocks.

Disturbance and Plant Succession in the Subarctic

In DNPP revegetation projects, our goals are (1) to simulate the natural process of plant community development following disturbance and (2) to speed up that natural process. An understanding of natural disturbance and plant community succession guides the revegetation of sites with human-caused disturbances. The landscape of DNPP is dynamic, with many types of natural disturbances that change the landscape and the plant communities. Natural disturbances in the park include:

- Wildfire—in interior Alaska, most white spruce forests burn before trees reach 250 years of age, but tree line stands burn less frequently. Black spruce forest has an average interval of 80 years between fires.
- River erosion and deposition—rivers and streams erode banks and deposit gravel, sand, and silt to form new floodplains.
- Glacial outwash—glacial meltwater deposits gravel, sand, and silt.
- Glacial recession—receding glaciers expose new areas for plant colonization.
- Mass wasting—landslides are very common in the park.

The development of plant communities on disturbed sites is referred to as plant succession. Primary succession describes the establishment of plants on substrates that previously had not supported vegetation. Examples of natural disturbances in DNPP and interior Alaska that create new substrates for primary succession include river erosion and deposition and glacial outwash (Viereck 1966, 1970; Walker et al. 1986).

Secondary succession is the reestablishment of vegetation on sites where it once existed, such as revegetation after wildfire or revegetation after the impacts of human trampling. Secondary succession often proceeds much faster than primary succession, as nutrients, organics, and propagules may remain in the soil after the disturbance and increase recovery rates. Some natural disturbances can result in both primary and secondary succession. An example of this kind of disturbance in DNPP is a landslide, where the upper portion may expose new substrate for primary succession, while the mixture of soil and vegetation at the bottom of the slide undergoes secondary succession.

Succession Following Wildfire. Although succession is complex and difficult to predict, there are general trends for succession following different types of natural disturbance in interior Alaska. Succession after a fire, for example, typically follows several stages (Van Cleve et al. 1986). In the first stage, light-seeded plants such as fireweed, willow, balsam poplar, and paper birch arrive and establish on microsites where mineral soil has been exposed. At the same time, many plants already present on the site, such as fireweed, bluejoint (*Calamagrostis canadensis*), rose, alpine blueberry, willow, paper birch, or quaking aspen, will sprout from stumps, roots, or rhizomes. Spruce seedlings establish and grow slowly.

During the second stage, the maturing shrubs and deciduous tree saplings may dominate, with spruce forming a low understory beneath them. Next, the deciduous hardwoods may form a dense canopy and shade the understory, leading to the invasion of shade-tolerant and soil-cooling moss. Heavy litter fall may temporarily inhibit moss invasion, but once shade-tolerant moss has established, conditions change. The soil cools and moss inhibits hardwood regeneration and the establishment of shrubby species. Spruce continues to grow as the hardwoods die out and fail to regenerate. During the third stage, after about 200 years, patches of hardwood remnants and a spruce forest are apparent.

Riparian Succession. The general pattern of riparian (e.g., along rivers and streams) succession in forested areas of interior Alaska is the establishment of herbs and willows (primarily feltleaf willow) as soon as the surface is sufficiently stable. A vigorous willow stand develops by 10 years, followed by increasing importance of alder and balsam poplar from 20 to 50 years (Viereck 1970; Walker et al. 1986). Balsam poplar dominates from 50 to 100 years, after which the understory of white spruce gradually gains dominance. All of the tree and tall shrub species which dominate different successional stages may establish together early in succession, but the

slower-growing, long-lived species gradually replace the fast-growing, short-lived species (Walker et al. 1986).

On tundra riparian areas, legumes (primarily *Astragalus*, *Hedysarum*, and *Oxytropis* sp.) and *Shepherdia canadensis* occur with or replace alder at the highest elevations, and the willow and alder stage is followed by low willows and dwarf birch, with an eventual shift to herbaceous tundra (Bliss and Cantlon 1957; Moore 1982). The nitrogen-fixing plants such as alder, legumes, and *Shepherdia canadensis* establish at early stages of succession and add nitrogen to the soil (Viereck 1966).

Human-Caused Disturbance. Human-caused disturbances, especially on a large scale, are relatively new to the Denali environment. Although native people traveled through the Denali region and used it as a hunting and gathering ground, they left few long-lasting traces of their use (Brown 1993). In this century, however, humans have introduced new disturbances to Denali. In the subarctic, an environment already characterized by poor growing conditions, human-caused disturbances can make plant establishment and growth more difficult. Types of human-caused disturbance include:

- Trampling and social trails.
- Road construction and maintenance.
- Construction of facilities.
- Abandoned roads and gravel pits.
- Mining activities.

Each of these disturbances change the natural environment in different ways. Trampling impacts are usually not severe, and an area can be restored relatively easily by, for example, closing it to further foot traffic. Construction disturbances are usually relatively easy to restore if revegetation was part of the original plan and soils and plants were actively salvaged. Abandoned roads, gravel pits, and placer mining disturbances limit plant establishment and growth the most and often present the greatest challenge to revegetate.

Gene Pool Conservation

One of the most important and least recognized resources of DNPP is the gene pool. Undisturbed plant communities have not been invaded by nonnative plants. Nonnative plants are confined to developed areas, primarily along the Parks Highway, the first 14 miles of the Park Road, and around facilities in the Kantishna area. Most of the nonnative plants are lawn and garden plants and agricultural weeds which have not spread beyond the disturbed sites where they were introduced. Nonnative plants which can easily be inadvertently spread to revegetation sites include the conspicuous and abundant dandelions (*Taraxacum officinale*).

Conserving the gene pool requires not only keeping nonnative plant species from establishing in the park but also requires that the native plants used on a site be genetically similar to the plants in adjacent undisturbed areas. We recommend the following general rules for collecting seeds and cuttings and transplanting sod or individual plants:

- The collection site should be within a 6-km radius of the disturbed site. This can include material outside the park boundary.
- The collection site should be within the same general broad vegetation type. Species that occur over a wide range of habitat types often have habitat-specific ecotypes which are genetically distinct. For example, within 3 km of park headquarters alpine blueberry occurs from forest to high alpine tundra. Blueberries for a disturbed forest site should be transplanted from a forest site.
- The collection site should be free of nonnative species.

These recommendations are based on the fact that the species that we use in revegetation have the potential for long distance dispersal of their genes. They have wind-dispersed pollen, wind-dispersed seeds, or animal-dispersed seeds.

Planning a Revegetation Project

The first steps in a revegetation project are to analyze the site characteristics that affect plant establishment and growth, and to set revegetation goals. Different project goals and site characteristics require different techniques, and we provide some general guidelines about how to analyze a site, diagnose its needs, and prescribe a strategy to restore it based on its revegetation potential.

The revegetation potential of a site may vary for specific plants and for specific stages in a plant's life, such as in the establishment or growth stages. For example, alder has difficulty establishing naturally on regraded placer mine tailings, but if seedlings are planted, alders grow with vigor. Therefore, the revegetation potential of placer mine spoils is low for alder establishment but high for alder growth.

Several steps should be taken to choose the right technique for a specific site:

1. Assess the severity of the existing or proposed disturbance.
2. Assess the abiotic factors (i.e., topography and soil) that help determine the revegetation potential of the site.
3. Assess the biotic (i.e., surrounding vegetation) factors that help determine the revegetation potential of the site.

4. Consider the goal (i.e., soil stabilization, aesthetic improvement, restoring ecosystem functions) of a proposed revegetation project.
5. Choose a technique.

Assessing Severity of Disturbance

Disturbance can be classified into three levels: light, moderate, and severe. **Light disturbance** damages or destroys vegetation but leaves the organic mat (the O horizon, see Fig. 2) intact. Because the organic mat contains most of the nutrient capital, as well as propagules, the revegetation potential of lightly disturbed sites is high, and the sites require little if any assistance to recover. Most plant species in the subarctic, however, require mineral soil (A or E horizon, see Fig. 2) for seedling establishment, so the presence of the organic mat will inhibit the invasion of plant species not able to reestablish from sprouts or buried seed.

Moderate disturbance removes the organic mat and exposes the top layer of the mineral soil (A or E horizon, see Fig. 2). Sites with the top layer of the mineral soil exposed have a high revegetation potential, especially from off-site seed sources or assisted revegetation.

Severe disturbance exposes subsurface materials (B and C horizons, see Fig. 2) that are usually coarse, nutrient-poor, and have a low ability to hold moisture and nutrients. The revegetation potential of severely disturbed sites is typically low.

Light and moderate human disturbance are equivalent to natural disturbances (e.g., wildfire) that initiate secondary plant succession, while severe human disturbance is equivalent to natural disturbances (e.g., glacial recession) that initiate primary plant succession.

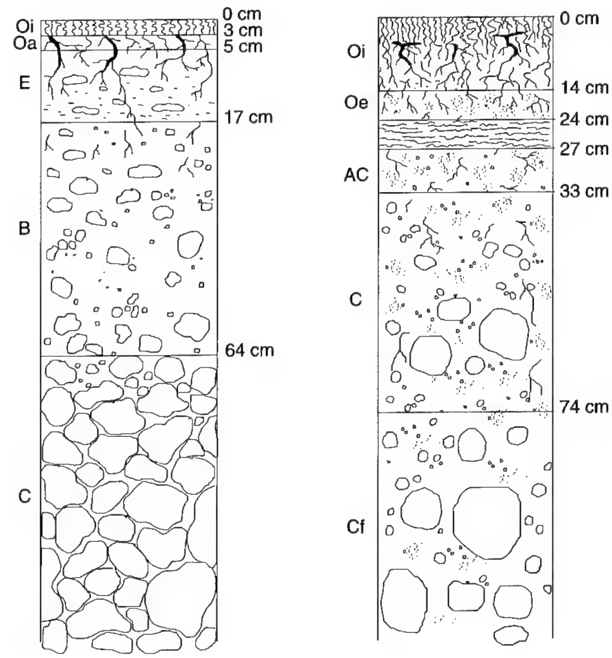

Fig. 2. Generalized sample soil profiles based on data from DNPP. The soil profile on the left is typical of well-drained, stable landforms with complete vegetative cover. The soil profile on the right is typical of poorly drained soils where frost action churns and blends soil horizons. This soil is underlain by permafrost. O horizon = an organic layer of fresh and decaying plant material at the soil surface (i = slightly decomposed, e = moderately decomposed, a = well decomposed); A horizon = dark-colored layer at or near the surface which is composed of a mixture of mineral soil and organic matter; E horizon = light-colored layer at or near the surface that is composed of mineral soil from which organic matter and some minerals have leached; B horizon = transitional layer which includes minerals leached from upper layers; C horizon = weathered parent material (f = frozen); AC horizon = mixed A and C horizons.

Assessing Abiotic Site Characteristics

The first step in planning a revegetation project is to identify the abiotic (nonliving) factors that limit plant establishment and growth and determine the revegetation potential of a site. In this section, we describe limiting abiotic factors and their secondary effects.

Topographic and Microtopographic Influences

Slope and Aspect. Plant communities in the park vary significantly with slope and aspect due to the high latitude and the ensuing low solar angle. South-facing slopes receive more solar radiation than north-facing slopes, while east- and west-facing slopes receive intermediate amounts of radiation. Higher solar radiation produces higher air and soil temperatures, earlier snowmelt, and drier soils.

Elevation. The length of the growing season and air and soil temperatures during the growing season decrease with elevation.

Microtopographic Influences. If a revegetation project is using seeds for plant initiation, the site must have microsites which are suitable for catching seeds, seed germination, and seedling establishment. Without proper microsites to host seeds, any effort to foster natural seeding or to assist seeding may be ineffective; creating microsites may be one necessary precursor to revegetating a site. In practice, the problem on severely disturbed areas such as road cut slopes and gravel pits is usually a soil surface that is too smooth; this problem can be eliminated in the design phase or improved later by

creating a rough soil surface by ripping or with hand tools (see Site Preparation section).

Soil Characteristics

Stability. The first soil characteristic to evaluate is stability. Erosion or mass wasting can occur on lightly, moderately, or severely disturbed sites but is most common on severely disturbed sites. Placer mine disturbances and road cut or fill slopes are especially vulnerable to substrate instability. Obviously, if the soil is eroding or moving, plants cannot take hold. Generally, five factors influence soil stability (Howell 1987):

1. Degree of slope—slopes greater than 5% are more likely to cause problems and require stabilization.
2. Type of soil—organic soils are generally more stable than mineral soils.
3. Soil texture and drainage—gravelly and sandy textured soils drain well and are less erodible than silty or clayey soils.
4. Moisture—the greater the level of moisture in the soil, the more likely it is to erode.
5. Permafrost—the presence of permafrost causes drainage problems and increases the potential for soil erosion.

Compaction. Soil compaction occurs when vehicle or foot traffic reduces the spaces between soil particles. The effects of compaction are decreased soil oxygen, reduced infiltration of water, and a barrier to root penetration. In general, coarse soils tend to compact less severely than fine soils. Areas likely to be compacted include old roads and gravel pits. Compaction can be reduced by ripping an area to a depth of 25-50 cm with heavy equipment or by hard work with hand tools.

Soil Texture. Soil texture refers to the relative proportions of cobbles (63.5-254 mm), gravel (2.0-63.5 mm), sand (0.05-2.0 mm), silt (0.05-0.002 mm), and clay (< 0.002 mm) (particle sizes are U.S. Department of Agriculture (USDA) classification). Soils with more fines (soil-size particles < 2 mm in diameter, which includes sand, silt, and clay), and/or more silt and clay in the fines, retain moisture and nutrients better than soils with coarser particles. Densmore (1994) describes the relationship between revegetation and soil texture for samples from Kantishna in DNPP. Plants in DNPP can grow well in soil which is 70% cobbles and gravel, provided that the fines fraction is at least 30% silt and clay (USDA soil textural classification, sandy loam) and that some organic matter is present (see Organic Matter section).

pH. Soil pH refers to the relative acidity or alkalinity of the mineral soil. Soils with a pH of 7.0 are neutral; values less than 7.0 are acidic, and values greater than 7.0 are alkaline. Values between 5.0 and 7.5 are characteristic of soils with good revegetation potential (Densmore 1994). Very acidic soil, such as that with a pH of 2.8 measured in DNPP on mine spoil contaminated with acid-forming minerals, cannot support plant growth. In DNPP, soils with a pH greater than 7.5 are characteristic of subsoil with a low revegetation potential due to a lack of organic matter and available nutrients.

Organic Matter. The proportion of organic matter in the mineral soil fines (< 2 mm) is important. This organic matter supplies nitrogen and helps retain nutrients and moisture in the soil. Soils in DNPP with organic matter values greater than or equal to 3% have high revegetation potential, whereas soils with values less than 1.5% have low revegetation potential (Densmore 1994). It is important to note that this soil characteristic is distinct from coarse undecomposed organic material which may be present in the surface organic layer or mixed in with the mineral soil.

Nutrients. Nutrient availability is affected by parent material composition, soil texture, decomposition rates, soil temperature, and the presence of nitrogen-fixing species. Nutrient levels are relatively low in the subarctic and may limit plant growth. The nutrients most likely to be limiting are nitrogen and phosphorous. We found that measurements of total nitrogen and available phosphorous in the fines fraction of the soil were good predictors of revegetation potential in DNPP (Densmore 1994). The proportion of organic matter in the fines (see Organic Matter section) is strongly correlated with total nitrogen and can be used as a surrogate measure. In contrast, we have found that measurements of soil nitrogen as nitrate and ammonium ion concentrations varied throughout the growing season and with microsite, and were not good predictors of revegetation potential.

Moisture. Soil moisture is influenced by soil texture, precipitation, topography, microtopography, snowpack, and rates of evapotranspiration. In spite of low precipitation, soil moisture is high in many subarctic areas because of low evapotranspiration rates and frozen ground which limits drainage. Areas likely to be dry include sites with well-drained, coarse-textured soils (which includes many human-disturbed sites), south-facing slopes, and windy alpine areas, where quick drainage and/or desiccation can inhibit plant establishment and growth.

We have not found an effective way to measure soil moisture directly on disturbed sites in DNPP. The rocks in the soil make standard soil measurement techniques difficult and inaccurate; however, we have found that measurement of field capacity is a good predictor of revegetation potential. Field capacity is the volume of water held within a given volume of soil after the soil has been saturated and allowed to drain for 24 h (for methods, see Densmore 1994). The field capacity of soil on disturbed sites is largely related to the amount of silt,

clay, and organic matter in the soil. Therefore, if measurements of soil texture and organic matter indicate high revegetation potential, the field retention capacity of the soil is adequate for revegetation.

Measuring Soil Characteristics. Soil samples can be taken from revegetation sites for analysis. We usually divide the site into areas which appear to have different soils and take a composite sample from each area for analysis. For the composite sample, we take two or more samples from the area and mix them into one sample. Each sample is taken from a hole 15 cm^2 and 15-20 cm deep. The following soil characteristics should be analyzed:

- Overall texture—the percentage of cobbles, gravel, and fines present.
- Texture of fines—the percentage of sand, silt, and clay present.
- pH.
- Organic matter—the percentage of organic matter in the fines portion of the soil sample.
- Total nitrogen—measured on fines portion.
- Available (also referred to as extractable) phosphorous. The extraction technique used depends on the soil pH.

We have had our soil samples analyzed at the University of Alaska soils lab at Palmer. Engineering labs often use a different classification system for soil particle sizes, which is confusing. For more information on soils and soil analysis, we recommend consulting any standard text for a college soils course or books that specifically address soil analysis, such as Carter (1993).

Assessing Biotic Site Characteristics

The second step in planning a revegetation project is to consider the biotic (living) factors that affect revegetation strategies.

Vegetation

Examine the vegetation on and around a disturbed site to provide the following information:

- What the target plant community should be, if restoration to predisturbance conditions is the primary goal.
- The pattern and rate of natural revegetation in disturbed areas within this vegetation type.
- The species likely to disperse seeds onto the site.
- Which revegetation methods will blend the disturbed site into the surrounding landscape to make a site visually attractive.

Using Natural Areas as Guides

Some human-disturbed sites are so altered that the predisturbance vegetation cannot be restored. In these cases, look for natural areas where site conditions are similar to those of the disturbed site. These sites will indicate which plant communities could develop on the site and which species should be used for revegetation. Examples include:

- Vegetation on gravel fill is usually more similar to vegetation on gravel river bars or stony, steep slopes than to surrounding undisturbed vegetation.
- Vegetation on road cut slopes greater than 1.2 m in height is usually more similar to vegetation on steep slopes (within the same geologic formation) than to surrounding undisturbed vegetation.

Presence of Propagules

The plant community which develops on a disturbed site is dependent on the available propagules. The following information may be helpful in deciding which propagules will be present on a site and which propagules should be added:

- Willows, quaking aspen, balsam poplar, and fireweed produce numerous small seeds which are dispersed by the wind for at least 1 km.
- Paper birch, alder, and white and black spruce produce larger seeds which are dispersed for 0.2-0.4 km.
- Seeds of plants which produce fleshy fruits, including *Shepherdia canadensis*, rose, alpine blueberry, lingonberry, crowberry, and bearberry, are usually dispersed in animal droppings. Dispersal is unpredictable.
- Some plants, including legumes, have relatively large seeds without any obvious means of long-distance dispersal. These plants may not colonize disturbed sites unless they are growing close by.
- Quaking aspen and balsam poplar will spread into a disturbed site from root suckers.

Setting Goals

The goals of a specific project are often the greatest influence on the choice of a revegetation technique. In DNPP, six basic goals drive the demand for revegetation activities:

1. Erosion control.
2. Improvement of visual quality.
3. Restoration of ecosystem functions (i.e., nutrient cycling, habitat value).
4. Prevention of exotic plant infestations.
5. Creation of screens so that disturbed areas are less visible to visitors.
6. Creation of barriers to protect disturbed areas from trampling and vehicles.

To efficiently restore a disturbed site, choose the technique that involves the least effort and expense, yet

adequately achieves the planned goals. For example, in 1990, when DNPP's new visitor access center was constructed, taiga mats were salvaged and transplanted to revegetate the area around the new building. The project designer chose to salvage, rather than rely on plants growing more slowly from seed, because immediate visual improvement was the project's primary goal. On the other hand, a similarly disturbed site near the park airstrip, out of view from visitors, was revegetated with a slower-growing, less expensive mix of legume and grass seeds.

Choosing a Technique

Once the goals of a revegetation project are determined, a set of techniques can be chosen and project objectives can be clarified. Project objectives, as opposed to goals, should be site-specific and detailed in order to quantify successful completion of the work. For example, an objective could be to "plant 350 alder in this area," or to "construct a brush bar from this stake to that stake."

Tables 1 and 2 provide a general guide for choosing revegetation techniques. Table 1 lists characteristics of sites with high and low revegetation potential. Many sites will be intermediate, or will have a mixture of favorable and unfavorable characteristics. The technique options in Table 2 are based on simplified goals common to many revegetation projects.

Revegetation Techniques

This section contains a "how-to" guide to revegetation techniques we have found to be useful in Denali National Park and Preserve. Each technique can be used in a variety of ways, and the following directions should be considered guidelines rather than prescriptions. A completed revegetation project is not really finished until it has been adequately protected from further disturbance so we have also included a section on project protection techniques.

Selection of Revegetation Species

Selection of species for use with revegetation techniques is based on observations of plant communities on natural- and human-disturbed areas in DNPP and from existing information on the revegetation potential of some species (Densmore et al. 1990). In interior Alaska ecosystems, early colonizers include species present only in the early stages of succession and many of the dominants of the mature plant community. Other species present in the mature plant community, particularly nonvascular plants, are difficult to include in restoration projects because they require the organic layer which builds up during succession and the interrelated changes in the soil thermal regime. Criteria for species selection:

- The species has relatively high density, cover, and/or visual appeal.

Table 1. Site characteristics indicating revegetation potential.

High revegetation potential	Low revegetation potential
Low elevation	High elevation
Site sheltered	Site exposed to high winds; snow blows off in winter
Organic layer or mineral topsoil present	Subsoil (C horizon) exposed or subsoil fill, low or no organic material in soil
No or minor erosion	High potential for surface erosion or slumping
Soil has relatively high field capacity	Soil has low field capacity
Soil has relatively high levels of total nitrogen and available phosphorous	Soil very low in total nitrogen and/or available phosphorous
Natural disturbance infrequent (e.g., upland forest)	Site subject to frequent natural disturbance (e.g., active floodplain)
Site well-vegetated prior to disturbance	Site sparsely vegetated before disturbance
Propagules present on or near site	Propagule sources limited

Table 2. Technique options based on revegetation potential and goals.

	High revegetation potential					Low revegetation potential				
	Visual quality	Erosion control	Ecosystem functions	Exotics control	Screen barrier	Visual quality	Erosion control	Ecosystem functions	Exotics control	Screen barrier
Natural revegetation	x		x					x		
Legume/grass seedings				x		x		x	x	
Annual ryegrass		x					x			
Mats							x			x
Salvage and transplant	x	x	x	x	x	x	x	x	x	x
Bioengineering		x	x				x	x		
Container-grown plants	x	x	x		x	x	x	x		x
Alder seedlings				x	x	x		x	x	x
Willow cuttings					x	x		x		x
Autumn seed blitz	x		x	x						

- The species naturally revegetates disturbed areas, particularly those having harsh site conditions.
- There is evidence that the density of the species is limited by propagule presence or seedling establishment.
- The species is relatively easy for nonspecialists to identify in the field, and seeds are easy to collect.

Natural Revegetation

Natural revegetation is the best option wherever there is not a strong reason for assisted revegetation because it does not interfere with natural processes and plant communities and does not risk altering the gene pool. Two effective ways to promote natural revegetation are to salvage and replace topsoil (see Salvage and Transplant section) and to rip compacted sites to a depth of 20-50 cm. Sites with replaced topsoil often revegetate well without further assistance.

Legume and Wheatgrass Seeding Technique

One successful revegetation technique is the *legume and wheatgrass seeding technique*, which involves direct seeding of several species of legumes and grasses onto disturbed areas. Site-specific native plants make up the legume and wheatgrass seed mix and plant community. These include species of the legumes *Hedysarum*, *Oxytropis*, and (occasionally) *Astragalus*, and species of wheatgrass (*Agropyron* sp. [= *Elymus* sp.]).

There are several species of *Hedysarum*, *Oxytropis*, *Astragalus*, and wheatgrass found in the park at different elevations and in various plant community types. The most common species of *Hedysarum* in DNPP is *H. alpinum*, which is found in two habitats—on river banks and bars as an early successional species and in upland tundra. The showier *H. mackenzii* (= *H. boreale* ssp. *mackenziei*) is also present on river banks and bars. *Oxytropis campestris* is common on dry, sandy sites throughout DNPP and is also common on river bars. *Oxytropis borealis* is another legume of dry sites which is abundant on gravel bars of the Toklat River. *Astragalus alpinus* and *A. eucosmus* are less-common legumes found on gravel and stony slopes. All of these legumes fix atmospheric nitrogen into a form useable to plants through an association with *Rhizobium* bacteria, enabling them to grow on nutrient-poor soils and to add nitrogen to the soil. The wheatgrasses *Agropyron macrourum* (= *Elymus macrourus*) and *A. violaceum* (= *E. alaskanus*) both grow on sandy and gravelly river banks and bars.

All of these species are common colonizers of roadsides and other disturbed areas in DNPP which resemble their natural habitats (Fig. 3). All of these species produce a relatively small number of large seeds which are not readily dispersed long distances by natural agents; therefore, human-disturbed sites usually take 8-10 years or longer to naturally revegetate with these species. Direct seeding greatly speeds up this process. Furthermore, we demonstrated in field experiments that a ratio of direct-seeded seeds to established plants is relatively low for these species Densmore et al. (1990).

Where to Use the Legume and Wheatgrass Seeding Technique

We have used the *legume and wheatgrass seeding technique* successfully on well-drained, nutrient-poor soils with high gravel and sand content (Figs. 3-6, seeding technique explained in Five-Year Results section). The seed mix is especially useful on roadsides, as it is aesthetically pleasing and satisfies roadside safety concerns because it is low-growing. The established legume and wheatgrass plant community can tolerate

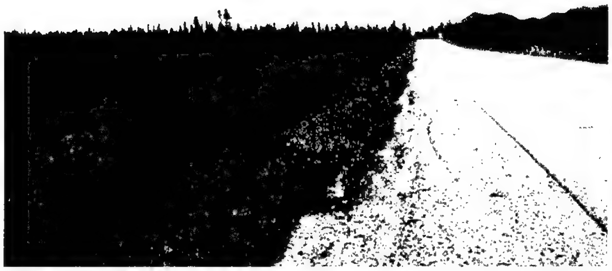

Fig. 3. *Hedysarum alpinum* naturally revegetated the road fill slope near the 13-mile marker on the Park Road. This community developed naturally over a 20-year period but has since been reduced by road maintenance.

Fig. 4. *Hedysarum alpinum*, *Oxytropis campestris*, and wheatgrass plants seeded on road fill.

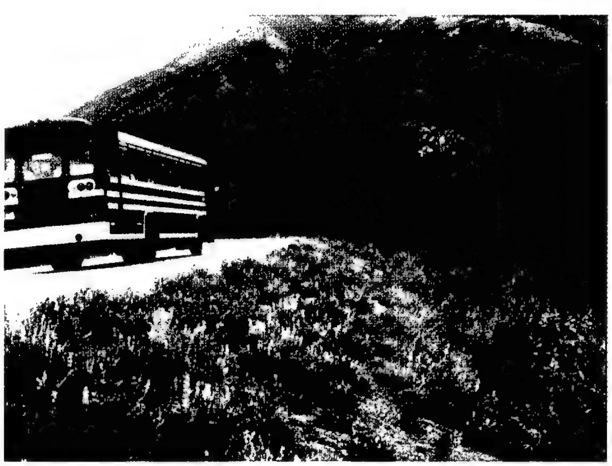

Fig. 5. Park Road fill slope 5 years after seeding with legume and wheatgrass mix. *Oxytropis campestris* was the main species flowering when this photo was taken.

Fig. 6. Park Road cut slope near the 20-mile marker 3 years after seeding with *Oxytropis campestris*, wheatgrass, and annual ryegrass. A brush bar was constructed the year following seeding to stabilize a slump. Sprouts from feltleaf willows buried in the brush bar grew vigorously (meter stick in photo for reference).

mowing and light scraping. It is very resistant to invading exotic plants such as dandelions. The legume and wheatgrass seeding technique is inexpensive to apply relative to other techniques because seeds are easy to obtain and labor costs are low.

Limitations

Patience is the key to growing native plants in the subarctic. The legume and wheatgrass growth will not be impressive for the first or even second growing season. The third and fourth seasons should yield striking results, and mature sites should provide an excellent seed source for future revegetation projects. This slow growth means that the legume and wheatgrass mix does not provide erosion control for the first two growing seasons. Erosion control can be provided by seeding annual ryegrass *Lolium multiflorum* (= *L. perenne* ssp. *multiflorum*) with the mix and/or installing erosion control mats or bioengineering structures (see Erosion Control Mats and Bioengineering section).

Seed Collecting and Handling

Where to Find Seeds. The seeds of *Hedysarum*, *Oxytropis*, and wheatgrass are easily identified, harvested, and stored. They can be found along roadsides, river banks, and gravel bars, and other places where disturbance is common. An example of a cultivated legume and wheatgrass plant community can be observed along the first mile of the Park Road and should provide abundant seed for many years (see Five-Year Results section).

When to Collect Seeds. The seed harvesting season usually starts in late July and lasts until late August. Harvest only ripe seeds. *Hedysarum* seeds are brown and papery and easily stripped off seed stalks when ripe. *Oxytropis* seeds are ripe when you can shake the seed stalk and hear the seeds rattle. The entire stalk should be harvested and kept in an upright position until placed in a bag, as the loose seeds will fall out of the open, vase-like pods. Wheatgrass seeds are ripe when they are light brown and scatter easily from the seed head when rubbed. The entire seed head can be harvested with scissors.

Drying Seeds. Dry the seeds and chaff thoroughly by placing them in a warm dry place for 1 week. Lay them out as flat as possible in trays. Adequate drying will prevent pathogens from damaging the seeds and reducing their viability. Inspect the drying seeds closely for evidence of insect damage. If a problem exists, place a no-pest insecticide strip on the drying seeds. This may decrease the damage to the seeds and will prevent roaming insects from becoming a nuisance indoors.

Cleaning Seeds. Separate the wheatgrass and *Oxytropis* seeds from the chaff by following three steps. First, place the seeds and chaff in a large cloth bag and kick it around a bit, or try placing the bag, along with several pairs of shoes, in a clothes dryer set on "no heat" and tumbling it for a time. Much of the seed will separate from the chaff and gravitate towards the bottom of the bag. Next, place the seed and chaff in a shaker box made of a milk crate lined with quarter inch mesh screen and shake the box over a garbage can. The seeds will fall through the screen, leaving the chaff behind. Further cleaning can be accomplished by winnowing (using a light breeze to blow the chaff away). *Hedysarum* seeds need no cleaning.

Scarifying Seeds. Some seeds need to be scarified to ensure germination. Scarification involves breaking down the seed coat to allow water absorption and gas exchange. In nature, scarification can happen by abrasion with sand and gravel. In the legume and wheatgrass mix, only *Oxytropis* seeds need to be scarified to increase germination rates. Do this by soaking the seeds in concentrated sulfuric acid for 10 min, stirring occasionally and rinsing them thoroughly. Another method involves rubbing the seeds lightly between two sand paper blocks. Care must be taken to avoid rubbing too much of the seed coat off.

Storing Seeds. Store the seeds for long periods by freezing. Label bags of seeds with species name, date collected, and location of origin. Unlabeled bags are useless and merely take up space in the freezer.

Site Preparation

As mentioned above, the legume and wheatgrass mix can be seeded with success on well-drained, nutrient-poor sites. A stable substrate is often the most important site-preparation concern. Slopes prone to sliding soil and erosion should be stabilized before sowing seeds. Work with the road maintenance crews to protect the toe of a slope from disturbance. Often, if the toe of a slope can be stabilized, the entire slope is held in position. Look for potential water erosion problems. Sites that catch runoff from a road are especially vulnerable to erosion and seed displacement. Use waterbars, terraces, and reinforced waterways where needed. Rubber-tired tractor tracks that function as contour furrows have provided erosion protection by catching water, seeds, and soil.

Soil compaction is usually not a problem for the legume and wheatgrass mix, but under extreme conditions, such as an abandoned road or gravel pit, a compaction problem may exist. To decrease runoff, increase water infiltration, aeration, and seed to soil contact, the soil can be scarified by ripping. Ripping can be accomplished using a tractor with ripper tines, a front end loader with a toothed bucket, or a backhoe. Ripping to a depth of 25-50 cm is usually sufficient.

Sowing the Seeds

When to Sow. The legume and wheatgrass seed mix can be sown anytime during the growing season, but sow in September (seeds will germinate the following spring) or May and June for the best results. Seeding in July and August may produce seedlings which are not well established before winter.

Seeding Rates. An average seeding rate is approximately 50 *Hedysarum* seeds/m^2, 50 *Oxytropis* seeds/m^2, and 100 wheatgrass seeds/m^2. Rates vary, however, depending on the objective of the project. For example, more seeds should be sown on steep slopes, and fewer should be sown in an area where colonization by other plant species is desired. The legume and wheatgrass community does not need to be homogeneous. Patches where the cream colored flowers of *Oxytropis* are dominant contrast nicely with stretches where the purple flowers of *Hedysarum* are in the majority.

How to Sow. *Hedysarum* seeds are most easily sown by hand, but *Oxytropis* seeds can be more difficult to handle because of their small size. A pepper shaker can be useful for broadcasting these seeds. Wheatgrass seeds can be broadcast using a hand-held seed spreader, although the slightest moisture will cause the seeds to stick together and render the spreader useless. Avoid seeding during windy periods.

Fertilizer

Fertilizer is useful for the establishment of the legume and wheatgrass plant community. Although the legumes fix nitrogen, they often need additional phosphorous for good growth. The grasses may need additional nitrogen for one or two growing seasons until the legumes are large enough to add significant amounts of nitrogen to the soil.

We have successfully used Osmocote, a slow release fertilizer, at a rate of 560 kg/ha or 56 g/m^2. Osmocote comes in a 1-year-release form and a 2-year-release form. Generally, the 2-year-release form is more desirable. The actual release rate may be slower under subarctic conditions because the release rate is temperature-dependent. The formulation we have used is approximately 14-14-14 NPK (percentages of nitrogen, phosphorous, and potassium), but a formulation with less nitrogen and more phosphorous would be more desirable because it would stimulate both legume and grass growth and decrease the risk of inhibiting legume nodule formation. One slow-release fertilizer we have tried with a suitable formulation is MagAmp (7-52-6 NPK), but we have had difficulty obtaining this fertilizer.

Using a slow-release fertilizer is important because it slowly releases nutrients nearer the rooting zone. In well-drained soils, the nitrogen in the common quick-release fertilizers often leaches out of the rooting zone before plants can use it (Densmore et al. 1987). This leached nitrogen can easily end up polluting the water table and streams. Quick-release, high-nitrogen fertilizers should also be avoided because they can deter the formation of nitrogen-fixing root nodules. Fertilizer can be applied efficiently using a hand-held spreader.

Raking

The final step of the legume and wheatgrass seeding technique is raking. Raking holds seeds in place and protects them from wind, water displacement, and herbivory, puts seeds in contact with the subsurface soil moisture, and may aid in scarifying the seeds, thereby increasing germination rates. The soil, seed, and fertilizer should be raked to a depth of 1-2.5 cm. This process is sometimes difficult in gravelly soils, but it is important to the establishment of the legume and wheatgrass community.

After seeding and raking on steep, unconsolidated slopes, such as newly constructed road fills, it may be advisable to run a small tractor equipped with wide tundra tracks up and down perpendicular to the contour. Using a small tractor has several advantages. The weight of the tractor with wide tracks should firm up the soil without causing excessive compaction, and tractor cleats will press the seeds firmly into the soil. In addition, the imprints from the tractor cleats create an enhanced microclimate, and those imprints running parallel to the contour of the slope will aid in erosion control.

Inoculation

Inoculating a revegetation site with the nitrogen-fixing *Rhizobium* bacteria is usually not necessary. However, if the site to be revegetated is composed of unusually sterile subsoil, inoculation may be helpful. To make the inoculant, dig up a nodulated legume and the soil that surrounds the legume roots. Chop up the roots, mix them with the soil obtained from the root ball, and sprinkle the mixture over the site. The site can be inoculated before or after seeding. Legumes should be examined for root nodules after they have reached maturity.

Seed Mix Additions for Landscaping

When aesthetics are a priority, the legume and wheatgrass mix can be seeded over an entire area, followed by plantings of colorful container-grown or salvaged flowers and shrubs. In this way, the visual quality of a site is immediately improved, and the bare ground between the planted flowers will fill in with the legume and wheatgrass plant community. Experience has shown that planted flowers and shrubs rarely colonize beyond their planting hole, leaving bare ground available for weeds (see Five-Year Results section). If the legume and wheatgrass mix is applied, it is important to plant flowers and shrubs either simultaneously with the mix, or plant flowers shortly after the area has been seeded (before the legumes and grass have germinated). Walking and working on seeds will not harm them, whereas walking on sensitive seedlings can be extremely damaging.

Grasses for Erosion Control

As mentioned previously, although the legume and wheatgrass mix is useful for erosion control, the plants may require an entire growing season or more to establish an adequate cover, leaving the site unprotected in the meantime. For immediate erosion control, we suggest using fast-growing, nonnative grasses which do not reseed themselves.

Annual Ryegrass

Annual ryegrass has been used successfully in DNPP for sites that require rapid erosion control. This grass dies at the end of the growing season and has not reseeded itself in DNPP. Annual ryegrass can be mixed with the legume and wheatgrass mix and/or seeded with container-grown seedlings.

Annual ryegrass can be seeded at any time of the year. The seeding rate should be 3.5-8.0 kg/ha or 130-300 seeds/m^2. Fertilizer is often needed to stimulate fast

growth for rapid erosion control. Again, a slow-release fertilizer is preferred. An application rate of 500 kg/ha for either slow-release or regular rapid-release fertilizer should be effective.

A tactic that may be helpful involves sowing annual ryegrass at a rate of 3.5-8.0 kg/ha or 130-300 seeds/m^2 along with the standard quantity of the native legume and wheatgrass mix. The mix should be sown near the end of the growing season, about mid-August. By sowing late in the season, the annual ryegrass germinates and reaches only a quarter to a third of its potential full height, then dies with the autumn frosts. The roots and stems from the annual ryegrass will provide some erosion protection and will not severely impact spring germination and growth of the native species. Irrigation may be necessary to ensure that the majority of the annual ryegrass germinates in the autumn.

On construction projects outside the national parks, the usual seeding rate for annual ryegrass ranges from 15 kg/ha to 30 kg/ha. We have reduced the usual rate for the following reasons:

- Dense live annual ryegrass can shade out native plants, including legumes and wheatgrass seeded with the annual ryegrass, container-grown plants and cuttings planted in the annual ryegrass, and naturally colonizing native plants.
- A thick layer of dead annual ryegrass can prevent native plant seeds from reaching mineral soil, including legumes and wheatgrass seeded on top of the annual ryegrass and naturally colonizing native plants.
- A thick layer of dead annual ryegrass can insulate the soil causing low soil temperatures and delayed or decreased germination and growth rates.
- Native seeds having a light requirement may not germinate under the darkness of a vegetation mat.

We derived our recommended seeding rate (3.5-8.0 kg/ha) from controlled field experiments in which we found that annual ryegrass seeded at 8.0 kg/ha did not inhibit native plants that were direct seeded or planted as container-grown seedlings (Densmore et al. 1990). We have subsequently used this rate on revegetation projects without any obvious detrimental effects on native plants.

Regreen

Another grass we have used for erosion control is Regreen, developed by Hybritech Seed International, Inc. Regreen is a male-sterile hybrid between wheat (*Triticum* sp.) and wheatgrass which will not set seed unless it can be pollinated by wheat growing nearby. We have tested Regreen at several locations in DNPP (Densmore et al. 1990). Regreen grew well when tested at elevations under 900 m, but growth was very slow at higher elevations. The optimum seeding rate was 150 kg/ha or 300 seeds/m^2. When compared to annual ryegrass, Regreen generally had a more negative effect on establishment and growth of native plants. For this reason, and because annual ryegrass is less expensive and easier to obtain, we have not used Regreen in revegetation projects.

Erosion Control Mats

Erosion control mats are commonly used on revegetation projects. The mats are usually made of organic fibers (straw, excelsior, or coconut fiber) held together with plastic or fabric netting. These mats are designed to be left in place. The coconut fiber is supposed to biodegrade, and the plastic netting is supposed to be photodegradable. Coconut fiber mats have been used in DNPP because the straw and excelsior mats can blow apart in windy sites, and the coconut fiber mats are the easiest to lift and reuse. There are many problems associated with using erosion control mats:

- The coconut fiber and the plastic netting degrade very slowly under subarctic conditions. Mats left out at Wonder Lake and Polychrome Pass only partially degraded within 10 years.
- Native plants cannot establish from seed on top of the mats.
- Seed germination and seedling growth are slower under mats.
- Once dicotyledonous plants have grown through the mat, it is difficult to remove the mat without damaging the seedlings.

Although we have had problems with coconut mats, procedures for using the mats with success include:

1. Seed, fertilize, and rake the slope using the standard rates of application. Seeding should be done in the late fall or early spring. As described earlier, annual ryegrass may be added to the mix. Tracks, depressions, and ridges should be removed to increase mat to soil contact.
2. Peg the mat securely to the ground.
3. Remove the mats as soon as germination of the legumes is evident. It is important to remove the mat as early as possible to avoid damaging the seedlings that may protrude through the mat. Grass seedlings may germinate before the legumes but will slip easily through a lifting mat, while the cotyledons, leaves, and multiple stems of legumes may cause problems. Removing the mat early is imperative for the growth and survival of the legumes and grass; however, the small plants may not be of any erosion protection value, and the site will be vulnerable to erosion until the plants are well established.

Plant Salvage and Transplant

Plant salvage involves recovering living vegetation or soil with propagules from construction sites and roadsides and using these plant materials to revegetate disturbed sites. Salvaged plants can be used to create barriers, stabilize slopes, improve visual quality, and prevent the spread of exotic vegetation. Plant salvage is shown in Figs. 7 and 8.

Plant material can be salvaged from construction sites, maintenance activities, and roadside ditches. The first and most important task is to acquire the plants before they are destroyed. Planting salvaged plants has several advantages over planting nursery stock or seeding in revegetation projects:

- Mature plants provide immediate improvement in visual quality.
- Large trees and shrubs provide effective screens and barriers.
- Transplanting, particularly with mats and clumps, is the fastest way to restore the predisturbance vegetation.

Tundra and Taiga Mats

Vegetation mats in the subarctic can host a great variety of species and growth forms, including moss and lichens, grasses and herbs, and shrubs and trees. Mats can be used effectively for many revegetation needs, such as filling in large areas of bare ground, forming a barrier to pedestrian and vehicular traffic, and providing

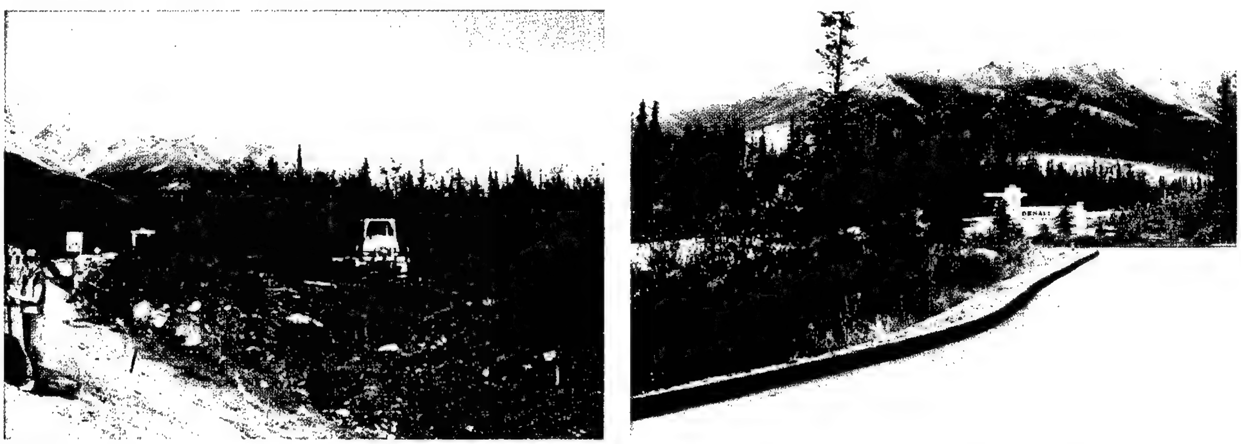

Fig. 7. The entrance sign parking lot during construction (left); the contractor mistakenly removed an island of vegetation between the parking lot and the road. On the right, the entrance sign parking lot 5 years after construction. All of the vegetation in the island between the parking lot and the road was salvaged and transplanted.

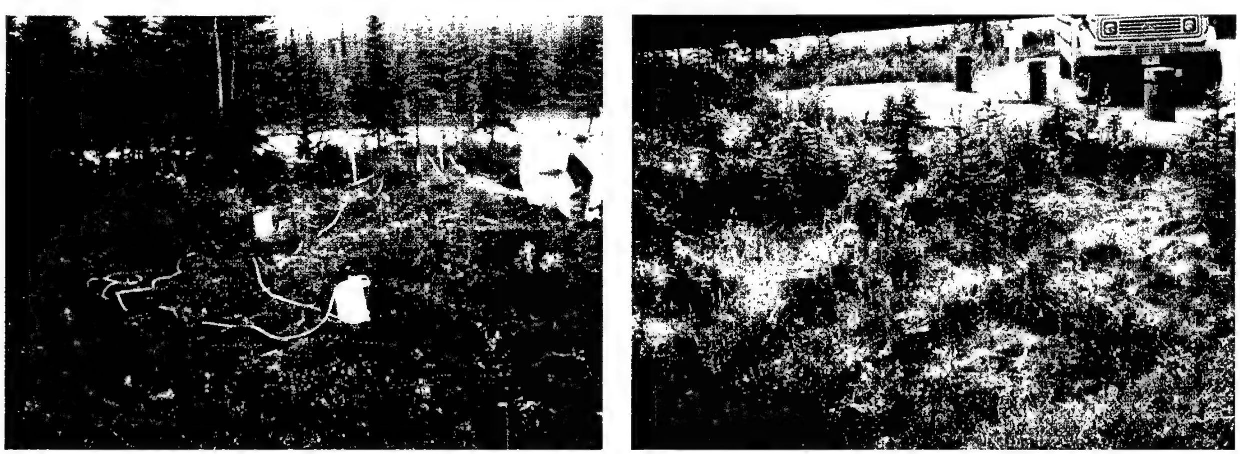

Fig. 8. Vegetation mat immediately after it was salvaged from the Visitor Access Center parking lot (left) and transplanted around the building. Note moss ground cover, dwarf birch, and small spruce trees. On the right, the same area 5 years after the mat was salvaged and transplanted. The dwarf birch and small spruce trees are growing well, but the moss has been replaced with grass and fireweed.

material to be used in bioengineering structures that stabilize a slope.

The following recommendations are for salvaging, transporting, storing, and transplanting vegetation mats:

1. With a pulaski tool, precut the vegetation mat to the desired size, which can be the size of a tractor loader bucket, or, if a tractor is not available, cut the mat into smaller pieces that one or two workers can handle. Attempt to cut the mat in such a way that the roots on the most valued plants remain intact. Root systems on most plants in the subarctic spread horizontally, rather than delve into cold or frozen soil, so the mats can be surprisingly large.
2. Scoop the mat up with a tractor or undercut and peel the mat by hand. Attempt to bring up as much of the rooting zone of the soil as possible. Effectively salvaging mats in the spring is sometimes difficult because a portion of the rooting zone may be frozen.
3. Transport the mats onto a flatbed low-boy trailer or pickup truck. Before depositing any mats on the trailer, cover the bed with a single section of engineer's cloth. To off-load the mats, position the trailer where you want to store the plants, and anchor the engineer's cloth in place by rolling the end of the cloth around a log or board. Chain the log to a solid anchor. Then, simply drive the trailer away, leaving the cloth and mats behind.
4. If properly salvaged and maintained, mats can be stored for several years. Eliminate gaps between stored mats by pushing them tightly together or filling in the spaces with soil. Keep the mats moist with a sprinkler or drip irrigation system. Mats with an intact soil layer and only minor root damage may need little or no watering while in storage. Prevent exotic plant contamination by avoiding areas where exotics exist, such as the headquarters area of the park.
5. To transplant a vegetation mat, excavate a depression deep enough to bring the mat to ground level. Scarify the soil in the depression to enhance root penetration. Fertilize the hole with a slow-release fertilizer. Fit the mat into the depression. To ensure good mat to soil contact, leave no air pockets. On a steep slope use rebar pegs to anchor the mat. Rebar pegs can also be used to anchor and secure any spruce trees that threaten to fall over within the mat. Fabricate L-shaped pegs about 50 cm in length for this purpose. Water transplanted mats to reduce shock and promote root growth.

Changes in Vegetative Composition. The vegetative composition of salvaged mats usually shifts after transplanting. Some change is due to root damage that leads to plant mortality. Root damage can be minimized by careful salvaging, which preserves the integrity of the mat and the underlying soil; however, transplanting always increases soil temperature and nutrient availability, and decreases soil moisture. These changes are analogous to those which occur after a wildfire, where the organic layer is scorched or partially burned and there is a decrease in moss and lichen cover and an increase in the growth of grasses and forbs (Fig. 8, see Vegetative Change in Transplanted Sod section). This is not necessarily bad because the new plant community is visually attractive.

Spruce Trees

Spruce trees can be salvaged almost anytime the soil is thawed, except in the spring when the trees are producing terminal branch growth. If you observe new, light-colored needles on branch tips, do not attempt to transplant.

White and black spruce are salvaged the same way as vegetation mats. A tractor is essential for this type of work. Typically, spruce roots spread horizontally well past the drip line of the canopy, so a rather large mat can be expected (Fig. 1). For example, a tree 3 m in height will need a mat approximately 3 m wide. A salvaged tree 4 m high is considered very large. Often several small spruce trees growing in a clump can be salvaged and transplanted together.

Trees to be salvaged without the assistance of heavy equipment should not be over 1 m tall. The mat or root ball on larger trees becomes too heavy for even the strongest workers to lift. An injured back and damage to the root system are usually the results of lifting large trees.

Small spruce (< 0.6 m tall) can be transported by placing them in large plant pots immediately after they are salvaged. The pots keep the soil and roots together and make moving them much easier. Spruce can be kept for several years in pots if care is taken in the potting process. Soil should cover the roots completely, with no airspaces. While in storage, potted spruce will require more maintenance, such as watering and weeding, than matted spruce.

Transplant salvaged spruce by digging a hole or depression slightly wider and deeper than the mat or root ball. Sprinkle slow-release fertilizer or place slow-release tree and shrub fertilizer tablets in the bottom of the hole and in the soil to be used as backfill. Place the spruce in the hole so that it stands unassisted. Backfill the hole and tamp the soil around the roots to ensure root to soil contact. If a spruce is properly planted, little support is needed later in the way of guy wires or rebar pegs. Leave a shallow watering moat around the planted

spruce and water it well with a transplant fertilizer solution.

If an unstable tree requires support, rebar pegs driven through the mat into the subsoil work better than guy wires. Guy wires are unsightly, can cut the legs of caribou and moose, and do not provide the mat to soil contact that pegs can. Tree stakes are also an option, but tree stakes and guy wires are more likely to induce tall, thin, weak growth.

Willows

Willow shrubs are extremely resilient and can be treated rather roughly compared to other plants such as spruce. Small willows can be excavated by hand and transported in pots. Larger willows can be scooped with a tractor and moved like a mat. The root balls on willows tend to be very heavy and sit well in planting holes. Transplant and fertilize willow in the same manner as spruce. Willows typically respond vigorously to fertilizer and will not need vertical support.

A procedure for salvaging and transplanting willow quickly entails digging the plants out of the ground with heavy equipment, storing the plants and root wads in a pile, then transplanting them by burying the stems and root wads in trenches or holes. The outcome can be temporarily unsightly, but the results are usually favorable. Running a bulldozer over the plantings not only tidies up the site, but also ensures good soil to root contact. This technique is especially applicable on new fill slopes and was employed on the mile 20 slump project in the park.

Soil Salvage

Soil, specifically the active layer, should be considered a collection of living organisms that can be salvaged, stored, and transplanted just like plant material. Salvaged soil can contain an abundance of propagules (roots, stems, rhizomes, and seeds) that when applied correctly can vegetate a disturbed site. We recommend the following steps for successful soil salvage, storage, and application:

1. **Remove stems.** Remove most of the living brush and stems from the area to be salvaged. Removing the live stems promotes sprouting, and it makes hauling and dumping the soil easier.
2. **Remove the soil with the appropriate machine.** A front-end loader is useful on level or slightly hilly terrain. A track hoe can salvage soil from steep slopes. A bulldozer can remove soil from most sites but cannot load it into a truck. Small jobs, or projects in remote areas, can be done with a mattock and shovel.
3. **Salvage the rooting zone.** Look for viable roots.
4. **Store salvaged soil carefully.** Transport the soil with a dumptruck and store it in a place safe from exotic plant infestation. Avoid compacting the salvaged soil with heavy equipment because many useful microorganisms are sensitive to the decrease in soil oxygen that results from compaction. Living soil cannot be stored for long and remain viable because buried propagules may decompose and lose their ability to germinate or sprout. Some seeds, however, can remain buried and viable for many years, including sedges (*Carex* sp.), raspberry (*Rubus idaeus*), and currants (*Ribes* sp.). To ensure maximum viability, the soil should be used the same season it was salvaged. Soil should be applied in the fall so as to take advantage of every hour of sunlight and warm temperatures in the spring. A soil pile stored over the winter will freeze solid and remain frozen well into the spring growing season.
5. **Prepare the site before spreading the soil.** For example, shallow (10-40 cm) trenches, furrows, or depressions can be excavated to hold salvaged root wads, or the site may be scarified to enhance soil mixing and root penetration.
6. **Apply the soil.** Spread 10-20 cm of salvaged soil and propagules over the disturbed site. Root wads and willow stems should be pushed into trenches and buried. Mixing the highly organic salvaged soil with the mineral substrate is essential. Alone, an organic layer would quickly desiccate and significantly decrease the chance of seedling and sprout survival. Decrease soil compaction while spreading the soil by using a small bulldozer equipped with wide tundra tracks. Some compaction is necessary to consolidate the soil, to increase soil to propagule contact, and to mix the salvaged soil with the underlying mineral soil.
7. **Dress the site.** After the soil has been dispersed and the propagules sufficiently mixed and buried, often no further action is needed. To hasten growth for erosion protection or aesthetics, however, the site can be treated with a slow-release fertilizer. The site can also be seeded with the appropriate grass, legume, shrub, or tree seed. It may be helpful to fertilize and seed the site after the soil has been spread but before the tractor has finished dressing the site to ensure the fertilizer and seed are incorporated thoroughly into the soil.

The enhanced water holding capacity, increased nutrient capital, and higher soil temperatures of the applied salvaged soil will facilitate seed germination, seedling survival and growth, and rooting and stem

sprouts from vegetative propagules. A soil surface roughened with salvaged organics will function as a seed trap, and the species composition of the restored site will hinge upon the propagules present in the salvaged soil and on neighboring seed sources.

Soil salvage projects completed before seed dispersal in the fall will experience advantages over those completed in the spring or midsummer because most colonizing species seed in the fall; however, most willows, aspen, and balsam poplar seed in the late spring.

Sprouts from willow roots and stems in the salvaged soil should be evident within a few weeks after spreading or in early spring. Fireweed and bluejoint grow from roots, rhizomes, or seeds and favor disturbed, nutrient-rich sites. Balsam poplar and quaking aspen sprout from root wads. Alder, dwarf birch, and alpine blueberry can also sprout but not as vigorously as the species mentioned above.

Buried seed in the salvaged soil may present a few interesting surprises. Little is known about the species composition and viability of buried seed in the subarctic; thus, every project where salvaged soil has been used should be monitored regularly to assess its success.

Bioengineering Techniques

Bioengineering is an approach to land stabilization that uses plants as engineering materials (Schiechtl 1980). Bioengineering involves the construction of living structures such as brush bars, hedge layering, and sodding that can stabilize and protect streambanks, floodplains, and steep slopes. These techniques have played increasingly significant roles in the revegetation and restoration efforts at DNPP. We are currently testing bioengineering techniques for stream and floodplain restoration on a placer-mined watershed in the Kantishna Hills region of DNPP (Karle and Densmore 1994a,b; Densmore and Karle 1999).

Bioengineering is not a new concept. It has been used extensively in Europe for many years and is now widely accepted in the United States. For agencies concerned with restoring for aesthetics, such as the National Park Service, it may become a preferred engineering tactic because it can replace structures such as retaining walls, terraces, rip-rap, and rock gabions. By building a protective structure that lives and grows, we establish a natural-looking entity that is self-maintaining and aesthetically pleasing.

Denali has an abundance of materials, such as willow and alder, from which bioengineering structures can be built. Feltleaf willow will sprout from cuttings and buried branches. Alder is more abundant but does not sprout. Nonetheless, we use alder where not enough willow is available to add mass, strength, and nutrients to a structure. Both species are often found conveniently near a revegetation project.

Brush Bars

Brush bars, sometimes called willow wattles or live fascines, are the most common type of bioengineering technique we have used at DNPP. Brush bars can be used to stabilize floodplains and slopes, assist sediment deposition, and to control gully erosion and improve drainage. The steps to construct a brush bar are listed briefly here and described in detail below:

1. Dig a trench of the desired depth, length, and width.
2. Lay anchoring ropes across the bottom of the trench at right angles to the trench. Branches will be placed on top of the ropes.
3. Lay a sproutable species of willow, such as feltleaf willow, in the trench along with some alder branches.
4. Backfill the trench with soil and rocks. This will cover the willow and anchor the brush bar.
5. Fertilize the backfill with slow-release fertilizer.
6. Weave alder and some willow into the bar until the desired height is reached.
7. Tie the bar together by squeezing the bundle of branches with the ropes laid down across the bottom of the trench.
8. Anchor the bundle with pegs.

The Trench. Digging the trench can be an arduous task, especially in compacted gravel and rock or on a steep slope. The trench can vary in size and placement according to the planned objective and the engineer's specifications. Generally, the trench is 30-46 cm wide and deep. If the trench is to be excavated by hand, a mattock and shovel are the tools of choice. Also, a backhoe or bulldozer with a six-way blade can save a lot of time and effort.

The Anchoring Ropes. The ropes laid across the bottom of the trench should be spaced at about 1-m intervals. Tuck the ends of the ropes under a rock or around a bush, as the rope ends can be accidentally buried in the construction process. The ropes should be made of a strong biodegradable natural fiber. Manila rope can be used but may lose strength after a year. The weakened rope should not cause major problems because the bar should be well rooted within a year, and the sprouting willow branches should hold the brush in place.

Placing the Brush. The two major objectives when placing brush into the trench are first to induce the willow to sprout, and second, to build strength into the structure. A bar constructed entirely of willow would be

ideal; however, we do not recommend harvesting plants from undisturbed sites, and disturbed sites usually have less willow than alder on them.

Willow branches should be used as soon as possible after cutting. Delays of less than 1 h between cutting and planting are recommended. If a longer delay is unavoidable, the branches can be preserved by laying the cut ends in a stream. Use willow and alder with basal diameters of 2.5-10 cm. Branch lengths can vary from shorter than the trench to longer than the trench by about a meter.

Place the willow branches in the bottom of the trench to ensure good soil contact. The terminal ends and lateral branches should be allowed to protrude out of the trench. The willow will sprout from these branches, protruding near the soil surface. Weave the branches together when placing them into the trench to give the bar strength. After the bottom layer of willows has been laid, weave in a mixture of willow and alder until the trench is full to ground level.

Live plants with intact root systems can also be incorporated into the brush bundle. Small willows, poplars, and alders can be yanked easily from gravelly soils and transplanted. These plants often grow well, even when transplanted so ungraciously. We have not tried planting container-grown alder seedlings inside a brush bar, but it should be tested.

Backfilling the Trench. Backfill the trench to anchor the brush bar and to give the willow a growing medium. The trench should be backfilled to 3/4 full; leave spaces for weaving in more brush. Shake the brush in the trench to fill air pockets and increase soil to brush contact. Water can be used for this purpose, and on drier sites, a good watering is highly recommended. A slow-release fertilizer should be added to the backfill at a rate of about 50 g/m of trench. Add the fertilizer slowly as you backfill the trench to ensure thorough mixing with the soil and brush. The backfill can also be amended with large rocks for stability and drainage, or with compost and topsoil to ensure that the willows sprout and grow with vigor.

Adding More Brush. Weave more brush into the bar, usually the more common alder, until the desired height above ground level is reached. Alder contributes mass, strength, and nutrients, while willow is saved for that part of the bar which needs to sprout.

Tying and Anchoring the Brush Bar. Tie the brush bundles together with the ropes that you laid across the trench earlier in the construction process. The ropes should be tied as tightly as possible by using a trucker's hitch. The ropes should hold the bundle firmly in the trench, with the weight of the backfill acting as an anchor.

Pegging the Bundle. Brush bars can be anchored with long sproutable pegs hammered through the bundle. Wooden pegs are often ineffective in rocky soil, whereas rebar can penetrate rocky soil. The rebar peg can be shaped to form a hook that holds the brush snugly in the trench. Pegs 50-75 cm long should be sufficient.

Pegs should be driven into the soil as deeply as possible at 1 m intervals. On extremely unstable slopes they can be spaced closer. Pegging the brush bar is not always necessary, especially on flat areas such as floodplains. The weight of the backfill and the quality of the branch weaving may be adequate to hold the bar in place.

Expected Succession and Maintenance. Do not expect horticultural miracles in the subarctic. Plant colonization and growth may be slow. Willow sprouts over 1 m high after one year's growth are exceptional; however, nutrients from fertilizer and alder branches and an enhanced microclimate within the bar will encourage a variety of pioneer species.

Little maintenance should be required. The bar should increase in strength each year as the willow sprouts hold the brush together and the roots consolidate the soil. In extreme conditions where quick growth is essential, fertilizer can be added each year.

Brush Bar Construction Guidelines for Specific Revegetation Goals

Floodplain Stabilization. Experimental work on abandoned placer mines on Glen Creek has generated techniques to stabilize floodplains and to restore predisturbance riparian vegetation (Karle and Densmore 1994a,b; Densmore and Karle 1999) (Figs. 9, 10, and 11). Brush bars are placed on the floodplain, perpendicular to the stream flow, approximately one stream-width apart. They are designed to control erosion and to encourage sediment deposition; willow roots hold the soil together and the aboveground alder branches decrease water velocity.

Lower water velocity allows sediment deposition within the bar and on the floodplain between the bars. Nutrients from the alder branches and the added fertilizer also improve plant growth. Pioneer species colonize within and adjacent to the bars, increasing plant diversity and stability as time goes by. Floods can be extremely forceful, however, so expect the loss of some structures.

When constructing brush bars for stream stabilization and revegetation, consider these points:

- Build the bars to the engineer's specifications. The engineer or hydrologist considers channel and floodplain design as well as flood frequency and intensity when deciding the length and placement of the brush bars.

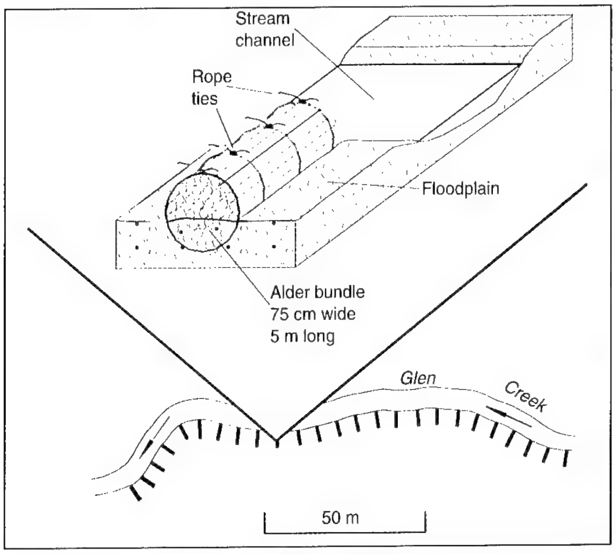

Fig. 9. Brush bar pattern on reconstructed floodplain, with one channel width spacing, along left bank of new channel reach at Glen Creek. Inset diagram shows typical installation of an alder and willow bundle, placed adjacent to the channel and anchored in the floodplain (from Karle and Densmore 1994a).

Fig. 10. Brush bars along channel reach (shown in Fig. 9) 6 years after installation. Note that vigorous willows and other plants are growing in and around brush bars.

- Build strong brush bars. The bar needs to be well built, as it will experience flooding and high velocity currents. Specifically, special attention should be given to digging a deep trench, anchoring with heavy rocks, and weaving branches well.
- Remove large rocks upstream. Large rocks within a meter upstream of a brush bar should be removed, as floodwater passing over these rocks will eddy and undermine the bar.

Fig. 11. Individual brush bar 6 years after construction, with feltleaf willow growing from sprouted buried branches (meter stick in photo for reference).

- Shape the bars to your needs. Brush bars need not be straight. They can be constructed to form V shapes, or built perpendicular to the stream, then extended downstream to wrap around a vulnerable streambank. Creativity is key in brush bar planning and construction.

Slope Stabilization and Drainage. Although we have had limited experience using brush bars to stabilize steep slopes, projects completed thus far demonstrate promise for future slope stabilization projects. Unstable slopes with sliding soil and rock or water erosion prevent plant establishment. Brush bars temporarily stabilize slopes, while the willows in the brush bar take root to provide long-term stabilization. Other temporary slope stabilization techniques, such as sowing annual ryegrass or using an erosion blanket, can be used with the bars.

In many areas along the Park Road, slope instability and the accompanying lack of vegetation is caused by road grading, especially grading away the toe of the cut slope. When the toe of a slope is removed, the substrate slides to seek its angle of repose, and material above the grading cut moves to fill in the missing toe. Many slopes would be vegetated if grading methods could be modified, or if a band of vegetation existed just above the toe. Those slopes naturally stabilized by vegetation or large rocks near the toe are usually not affected by grading. Vegetation can be seen colonizing these slopes above the vegetation clump. In many instances, the vegetation clumps originated at the top of the slope and slid down to their present position. Brush bars can be constructed to provide this same kind of slope protection. The brush bar built near mile 20 on the Park Road in mid-August, 1994, is good example of this technique (Fig. 6).

Slope stabilization brush bars can range in size according to the job at hand. The bar can be as small as four or five willow branches completely buried beneath the soil, to a full-sized willow and alder bundle that protrudes 50 cm above the soil. Such brush bars can be built on the contour to catch and hold moisture, or at a slight angle to direct water flow.

Gully Erosion Control. Gully erosion can present a serious threat to natural vegetation, roads, structures, trails, and revegetation projects. Wooden plank fences and terraces have been used for gully erosion control with mixed results. Brush bars can be applied to gully erosion problems with improved results and are also more aesthetically pleasing. Using branches instead of planks allows water to pass through the structure, leaving the soil drier and more stable. Proper drainage also minimizes the possibility of water undercutting the brush bar.

To build brush bars in areas with gully erosion, follow the construction steps previously described for slope stabilization and consider the following recommendations:

- If the gully in question is an obvious waterway, it may be prudent to divert water from the top of the slope or to construct a drain, or a rough, rock-hardened surface.
- A series of brush bars is usually necessary to do the job correctly.
- The brush bar trench must be at least 25 cm below the floor of the gully. This will prevent water from undermining the bar.
- The brush bar should be firmly keyed into the slope by extending the trench 1 m on either side of the gully. The trench for this type of brush bar can sometimes be over 1 m deep.
- Backfilling the gully behind the brush bar is recommended; excess material from the trenches may be adequate, or importing soil may be necessary. The bare soil uphill of the brush bar should be vegetated with seeds, salvaged plants, tundra mats, or container-grown plants.
- Soil, seeds, and dislodged plants should accumulate behind a properly constructed brush bar. Plant establishment and growth can be hastened by adding slow-release fertilizer to the accumulated soil and organic debris. As time passes, the brush bar should increase in strength, and the soil uphill of the brush bar should support pioneer plants.

Fig. 12. Feltleaf willows stabilizing streambank at Glen Creek 4 years after planting. Willow branches were laid horizontally perpendicular to the channel with branch tips projecting from the bank and then buried with soil. Flowers are dwarf fireweed (*Epilobium latifolium*), which revegetated naturally.

Hedge Layering

We have successfully used a technique similar to brush bar construction, sometimes called "hedge layering," for streambank restoration (Fig. 12). Gravelly soil was bulldozed to a level above the average stream water level to reconstruct the floodplain. Willow branches 2-3 m long were placed on top of the soil perpendicular to the channel with their branch tips projecting 0.5 m from the bank. They were fertilized with Osmocote and then buried with 0.3-0.4 m of soil.

This technique would also be useful for slope stabilization; it requires only a small terrace (25 cm wide) dug along the contour and densely stocked with cuttings or rooted plants. Lay cuttings or seedlings horizontally on the terrace, then backfill the terrace to the original slope angle, leaving the plant stems protruding. At DNPP, container-grown alder seedlings may be the shrub of choice. Site-specific alder seeds are easy to collect, and nursery-grown seedlings are relatively economical to propagate. They can be planted as close as 15 cm apart to create a stable strip of vegetation.

Sodding

Sodding is a bioengineering technique that uses vegetation mats for soil stabilization and erosion control. Tundra mats, taiga mats, and turf grasses have been used with success (see the Plant Salvage and Transplant section for more information).

As with brush bars, the major concern when using vegetation mats is anchoring them in place and inducing them to root. The following is a list of recommendations for using vegetation mats as bioengineering materials:

- To anchor mats to a slope, excavate a hole deep enough to bring the vegetation mat level to the ground. Then position the mat in the hole, and drive L-shaped rebar pegs through it into the soil beneath. Mats can be cut to form any shape desired. A shallow, narrow trench built along the contour of a slope and planted with a vegetation mat may become an effective terrace.
- Round and stabilize the top of a road or trail cut by excavating under the existing vegetation mat and allowing the mat to fold down and cover the slope. The mat should remain attached to stable vegetation and thus be held in place from the top. The mat can be pegged to prevent ripping and sliding. If this technique is used, it is important to stabilize the toe of the slope as well.
- Vegetation mats can be used as building bricks. Slice the mats into rectangular pieces and use them to construct a very steep, living wall. The bricks can be pegged to each other and to the underlying substrate. This technique may be useful around culverts or sunken walkways.

Container-Grown Plants

Container-grown plants are propagated from seeds and cuttings. Advantages and disadvantages of container-grown plants are listed in Table 3. We have used container-grown plants extensively at DNPP for the following types of projects:

- Revegetation projects that require immediate visual improvement.
- Projects on harsh sites that limit seedling establishment but not growth.
- Unstable sites where erosion is a major concern.

The container-grown species we have tested in DNPP revegetation projects are listed in the Species Tested and/or Used for Native Plant Revegetation section. Some of these species from various revegetation projects are shown in Figs. 13-18.

Propagation

Our propagation methods are based on standard horticultural practice; we suggest consulting recent editions of Ball (1985), Dirr and Heuser (1987), and Hartman et al. (1990) for additional information.

In the past, most container-grown plants were grown at the Alaska State Forest Nursery, and some were grown at the Alaska State Plant Materials Center in Palmer and the University of Alaska greenhouses in Fairbanks. The Alaska State Forestry Nursery is no longer in operation. In the future, container-grown plants would have to be grown at the Alaska State Plant Materials Center or the university facilities, both of which have limited space, or at commercial facilities. Construction of a small nursery and plant propagation facility at DNPP may be cost-effective.

Table 3. Advantages and disadvantages of container-grown plants.

Advantages	Disadvantages
Can be planted any time during the growing season	Expensive to propagate; cannot provide dense cover over a large area
Well-developed root system stabilizes the soil and resists washout, unlike seeding	Exotics and native plants from distant sources may be introduced if plants are propagated outside DNPP
Less transplant shock than salvaged and transplanted plants	Must be adequately maintained while in storage; requires a water source
Transport and planting is easier than with salvaged plants	After planting on site, weeds may invade propagation medium around plants and bare spaces between plants
More control over diversity, density, and spatial patterns	
Can be used for bioengineering	

Fig. 13. Shrubby cinquefoil is a low shrub which is propagated from cuttings. It is found in a wide variety of habitats in DNPP and colonizes disturbed areas. This plant is ideal for landscaping because it continues to flower throughout the summer. Horticultural cultivars of this species are widely planted.

Fig. 14. Container-grown *Solidago multiradiata* planted on road fill slope. This species grows throughout the park and colonizes disturbed areas.

Fig. 15. Container-grown *Arnica frigida* planted on fill. This species grows on open, rocky sites in tundra and subalpine areas and colonizes similar disturbed areas. Container-grown *Arnica alpina*, which grows at lower elevations, grows well around the park entrance and spreads from seed.

Fig. 16. Container-grown plants planted on salvaged topsoil placed on the new gravel pad of a renovated historic cabin. Purple flowers are *Aster sibiricus* and *Hedysarum alpinum*, and yellow flowers are *Senecio lugens* and *Arnica frigida. Aster sibiricus* spreads vegetatively once established. All of these species occur naturally in the subalpine meadow at the edge of the gravel pad.

Fig. 17. Container-grown *Aster sibiricus* planted on road fill.

Scheduling. Good planning and scheduling are important when container plants are used. Greenhouse schedules must be considered. In Alaska, greenhouses usually do not grow plants during the period of low light and temperature in midwinter. Most of the greenhouse space is closed down throughout the winter until propagation begins in February and March. Midwinter growth would require contracting to greenhouses farther south. Recommended schedules for different types of container-grown plants are shown in Table 4.

Symbiont Collection. Alder, *Shepherdia canadensis*, and the legumes (*Hedysarum*, *Oxytropis*, and *Astragalus*) should have the propagation media inoculated with nitrogen-fixing organisms which produce nodules on

Fig. 18. Container-grown *Elymus innovatus* (= *Leymus innovatus*) planted on an abandoned road. This species thrives on dry, gravel sites but is very difficult to seed directly. Container-grown *Calamagrostis purpurascens* also works well on these sites.

their roots. Dig under vigorous plants of the species to be propagated and get as many nodules as can be located easily. Put the nodules in a bucket of dirt from around the roots. If nodules are hard to locate, the dirt from around the roots should do the job. This also inoculates the plants with their mycorrhizal symbionts. Mycorrhizal inoculation may be beneficial for many species grown in containers, particularly woody plants from nutrient-poor sites such as dwarf birch.

Propagule Storage. Seeds and dormant cuttings should be kept frozen until used. In the park, cuttings can be stored outdoors. Dormant frozen cuttings desiccate easily, sometimes even inside a sealed plastic bag. Cuttings should be loosely packed in damp moss, vermiculite, or a similar moisture source and then placed in plastic bags. Putting snow in with the cuttings in the bags doesn't work as well but may be necessary if large numbers of cuttings are being stored.

Germination Tests. Many seed lots have a low proportion of viable seed, sometimes as low as 10%. It is important to know the proportion of viable seeds so enough seeds are put into each container to ensure that at least one seed germinates. Germination tests to determine the proportion of viable seed should be run on seeds before they are seeded into containers.

Seeding. The number of seeds per container is dependent on the quality of the seed. Seeding should produce two to three seedlings per container. The minimum seeding rate should provide at least one seedling in greater than 90% of the containers and two seedlings in at least 50% of the containers. Most Alaskan native plant seeds require light to stimulate germination; therefore, seeds should be placed on top of the soil in the container and left uncovered or covered lightly with translucent coarse sand or fine gravel. Many seed lots will be small, represent much collection time, and/or have a large proportion of seed hairs, bracts, and other nonseed material. Therefore, extra time and care should be invested in seeding containers.

Rooting Cuttings. Woody plant cuttings should be dipped in hormone rooting powder and rooted in a mist bed in a greenhouse (for willow and poplar cuttings, see Willow Cutting section). Details on propagation from cuttings are available in many standard references (Dirr and Heuser 1987; Hartman et al. 1990).

Containers. The best containers for seedlings are the book-style root trainer containers. The plastic containers fold together and lock and can be easily opened to remove the seedlings for planting. This is important because the perennial herb seedlings we grew in tube containers were so hard to remove that many were damaged. Root-trainer containers also have vertical grooves on the sides which encourage roots to grow straight instead of spiraling around the container. The tube-type containers are satisfactory for woody plants.

Propagation Medium. Seedlings should be propagated in standard horticultural propagation media, usually a combination of peat and vermiculite or perlite.

Fertilization. Container-grown plants can be watered in the greenhouse with standard greenhouse liquid fertilizer. We suggest reducing the concentrations of fertilizer in the watering solution to avoid stimulating shoot growth at the expense of root growth. Alders, *Shepherdia canadensis*, and legumes should be fertilized with a low nitrogen fertilizer because too much nitrogen inhibits the growth of nitrogen-fixing nodules.

Inoculation with Symbionts. The best method is to mix the inoculant into the propagation media before the media is placed in the containers. Inoculative organisms are dispersed through the media more thoroughly if the

Table 4. Recommended schedules for container-grown seedlings of perennial herbs and fast- and slow-growing woody plants, and for container-grown woody plants from dormant cuttings.

All perennial herbs and woody plants from seed	
Seed collection	July 15-Sept. 15
Seed storage	July 15-March 1
Germination tests	July 15-March 1
Sowing	March 1-April 7
Greenhouse	March 1-June 1
Thinning	3-4 weeks after planting
Move outside	May 15-June 1
Perennial herbs and fast-growing woody plants [a]	
Maintain	May 15 until planted; can be maintained outdoors for 1 year in the tube or root trainer types of containers
Plant	May 24-July 21
Slow-growing woody plants from seed [b]	
Maintain	Grow in containers outside for 1 year, then plant[c]
Plant	May 24-July 21; the second growing season after plants were started in greenhouse
Woody plants from dormant cuttings	
Collection	Sept. 1-March 1
Storage	Sept. 1-March 1
Root in mist bed	March 1-April 15
Plant in containers	April 1-April 21
Greenhouse	March 1-June 1
Move outside	May 15-June 1
Maintain	May 15 until planted; can be maintained outdoors for 1 or more years if pots are large enough for good root growth[c]
Plant	May 24-Sept. 15

[a]Fast-growing woody plants include alder, paper birch, balsam poplar, and willow.
[b]Slow-growing woody plants include white spruce, black spruce, dwarf birch, and *Shepherdia canadensis*.
[c]Plants are usually overwintered outdoors but can also be returned to the greenhouse for additional growth.

larger nodules are picked out and ground in a coffee grinder or blender.

Thinning. Seedlings should be thinned to one per container after the seedlings are well established and have their first true leaves (spruce seedlings may have just cotyledons when they are thinned). Thinning usually needs to be done 4-6 weeks after planting.

Hardening Off. Container-grown plants should not be planted straight from the greenhouse. The plants should be set outside in their containers, preferably in partial shade for 1 week before planting.

Transportation. Container-grown plants should be transported from the greenhouse in a covered vehicle and/or waxed closed boxes. Enclosed vehicles can become too hot, and large numbers of plants should be transported in a refrigerated truck.

Maintenance and Winter Storage

Container-grown plants need to be cared for until they are in the ground. Adequately watering the plants before planting is extremely important. Some plants, if allowed to wilt, may experience a severe setback in their ability to grow. Even if the plants regain turgor, the ability to take in carbon dioxide and convert it to plant tissue may be impaired for weeks. In the subarctic, where the growing season is short, inadequate watering may doubly stress container-grown plants.

Construction projects are often delayed. Plants in root trainer or tube containers can be maintained for at least a year, and plants in larger pots can be maintained for several years. Watering, of course, is important. Plants should be fertilized if they start to look nutrient-deficient.

Container-grown plants can be returned to the propagation facility for further growth or overwintered outdoors. The container soil must be moist at freezeup. The roots of plants may be injured if air temperature is very low (-12 °C) before the containers are covered with snow. Plant roots, even in interior Alaska, are usually insulated by soil and snow and never get as cold as air temperature. Container-grown plants, on the other hand, have their roots close to thin container walls and exposed

to the cold air. To protect roots, place all the containers as close together as possible. The outside row can be insulated with any convenient material—dirt, sawdust, peat, erosion control matting, etc. In years with good snowfall in October, plants are usually well protected.

Planting Container-Grown Plants

To plant almost any container-grown plant, the following guidelines should be helpful:

1. Excavate a planting hole deep enough to completely cover the roots and allow for a shallow watering moat. A mattock or hand pick are the preferred tools for planting.
2. Before planting, carefully examine the plants for exotic plant species, insects, and disease.
3. Check for root problems. Plants not grown in root trainer containers may have roots which spiral around the container, especially at the bottom of the container. To remedy this situation, it may be necessary to cut an "x" on the bottom of the root ball or slash the sides.
4. Plant the seedling and roots straight up and down. Do not contort the roots to make them fit an inadequately sized hole.
5. Cover all of the roots, as moisture can be wicked away through roots and potting soil exposed to the air.
6. Fertilize each plant with a slow-release fertilizer. If a nitrogen-fixing species is being planted, use a low-nitrogen fertilizer. Mix the fertilizer thoroughly with the backfill. The instructions that come with the fertilizer list the amount of fertilizer to use with different container sizes.
7. Water each plant with 1 L of a fertilizer transplant solution at one-half of the strength recommended on the container. This reduces transplant shock, stimulates root growth, and provides a small amount of readily available nutrients. These solutions are available at garden stores.

Alder Seedlings

Alnus crispa (= *Alnus viridis* ssp. *crispa*), a common alder species in DNPP, is useful for revegetation projects. Vigorous growth on harsh sites, the ability to fix nitrogen, easy seed collection, and simple propagation all make alder the species of choice for many revegetation projects. We found that feltleaf willows growing with planted alders used nitrogen fixed by the alders, which promoted vigorous willow growth on sites where the soil nitrogen levels were low. Feltleaf willows growing without alders on these sites were stunted or died. Alders have suppressed growth of other species on some sites in Alaska (Chapin et al. 1994; Walker et al. 1986). Alders on our sites have not suppressed willow growth primarily because the alder species we use (*Alnus crispa*) is shorter and grows more slowly at subalpine sites than the alder species studied by these authors.

Planting container-grown seedlings is the most efficient way to establish alder for two reasons. First, when alders are established from seed on a disturbed site, they usually grow slowly for 3 to 6 years and then more rapidly to mature height. Second, on some disturbed sites with very poor soils, alders have trouble getting started from seed, but they grow well once established. In the past, we grew seedlings at the Alaska State Forest Nursery in Palmer. Revegetation projects where we have used alder seedlings are shown in Figs. 19 and 20.

Collecting Seeds and Inoculant

Collect alder cones during the last week of August or the first week of September. Place the cones in a warm, dry place for 1 week to ensure complete drying. Remove the seeds by placing the cones in a container, for example a large coffee can, and shaking vigorously. The seeds will separate from the cone and gravitate towards the bottom of the container. Separate the cones from the seeds with a screen or a kitchen colander. Package the seeds in properly labeled plastic sandwich bags and store the seeds in a freezer.

Every seed lot should be accompanied by 1-4 L of alder root nodules and soil from the collection site. Alders form root nodules containing the microorganism *Frankia* sp., which fixes atmospheric nitrogen, converting it to a form of nitrogen useable to plants. Alder root nodules are shown in Fig. 21. The alder root nodules and soil surrounding the roots are used to inoculate the alder seedlings in the nursery. Label the inoculant and store it in a cool place. Do not forget this step. Soil inoculant is hard to procure in January in Alaska.

Germination Tests

Alders produce many nonviable seeds. The proportion of viable seeds ranges from 5 to 40%. We recommend germination tests to determine the number of viable seeds in a seed lot. It is usually necessary to plant 10-20 seeds per container to ensure that each container has at least one seedling. Most viable alder seeds will germinate at greenhouse temperatures without any pretreatment to break dormancy (Densmore 1979).

Propagation

We have successfully grown up to 10,000 alder seedlings in a greenhouse at one time. The following describes the propagation process:

Fig. 19. Former parking lot and construction staging area just after planting with alder seedlings and willow cuttings (left); and the same area 5 years later (right).

Fig. 20. Placer mine tailings (the gravel area) 7 years after the tailings were leveled and planted with experimental plots of alder seedlings and willow cuttings. The areas on the left side and left center of the photo were planted with alder seedlings and feltleaf willow cuttings. Feltleaf willows established naturally from seed near the planted alders and have overtopped the alders. The light green area on the right side is willow cuttings planted with slow-release fertilizer tablets. The empty area in front of these willows had unfertilized cuttings which died. The areas of the leveled tailing pile which were not planted are still barren after 7 years.

Fig. 21. Alder root nodules.

1. Start propagation in early March. Three months of greenhouse growth produces seedlings of optimum size (15-25 cm tall) for outplanting (Fig. 22).
2. Mix a batch of soil to be used as a propagation medium. The medium contains one part peat to one part vermiculite with a minimum of 2 L soil and nodule inoculant per 1 m^3 of mix.
3. Place the soil mix into containers and plant 10 to 20 seeds per tube. We have successfully grown

Fig. 22. Alder seedling in its container and feltleaf willow and balsam poplar cuttings.

alders in tube containers 2.5 cm in diameter and 10 cm long (Fig. 22).

4. Seedlings should be watered with a low-nitrogen fertilizer solution to promote nodule growth. We have successfully used a 7-40-11 NPK + micronutrients solution.
5. Thin the seedlings to 1 alder per container approximately 6 weeks after sowing. The alder take approximately 3 months to develop into plantable seedlings.
6. Harden off the seedlings by setting them outside of the greenhouse for approximately 2 weeks before planting. This will allow a time of adjustment between the cozy greenhouse and the harsh world.
7. We have transported seedlings in waxed boxes. Once in the park, the alders should be taken out of the boxes and stored in a place that receives partial sun, such as under a spruce forest canopy. Save the boxes to use again. Do not store seedlings anywhere near exotic plants. Container-grown seedlings need lots of water and should be monitored daily. If the seedlings need to be moved again, either re-box them for transport in the back of an open truck, or carry them inside a vehicle. Do not subject tender seedlings to wind in the rear of a truck.

Planting Alder

Alders are usually planted 0.5 m apart. When planting large bare areas, we have planted alders in clumps, leaving open spaces between clumps for colonization by other species that require bright sunlight. For goals such as floodplain or slope stabilization, alder can be planted in bands along the contour. One way to accomplish this is to construct a small terrace along the contour and lay the alder seedlings horizontally on the terrace. Leaving alder stems in the horizontal position, fill in the terrace back to the original slope angle.

The following directions for planting container-grown alder seedlings should be helpful:

1. Excavate a planting hole deep enough to completely cover the roots and allow for a shallow watering moat. The seedling and roots should be planted straight up and down. Do not contort the roots to make them fit an inadequately sized hole. Cover all of the roots as moisture can be lost through roots exposed to the air. A mattock or hand pick are the preferred tools for planting.
2. Fertilize each alder with a slow-release, low-nitrogen fertilizer; mix the fertilizer thoroughly with the backfill. We have used the slow-release fertilizer MagAmp (7-52-6 NPK). High nitrogen fertilizers can inhibit nitrogen fixation.
3. Water each alder with 1 L of a fertilizer transplant solution at half the strength recommended on the product. This will reduce transplant shock, stimulate root growth, and provide a small amount of readily available fertilizer.

Expected Results

We have experienced very high (usually > 95%) survival after 5 years for alder seedlings, with growth to a height of 1 m within 3 years.

Willow Cuttings

This section addresses using willow cuttings to establish willow plants. The use of large willow branches in bioengineering structures is addressed in the bioengineering section. Most willows are adapted to root rapidly after stems are buried by flooding and have dormant root buds all along the stems. These buds, called preformed root initials, are formed in each year's new shoot growth and are covered by wood in subsequent years. Cuttings from some Alaskan willows which grow primarily on upland areas do not root readily from root initials and are unsuitable for cuttings or bioengineering structures (Densmore and Zasada 1978) (Table 5).

We have used feltleaf willow cuttings in all our revegetation projects in DNPP for the following reasons:

- Feltleaf willow is the most common colonizing willow in DNPP.
- Feltleaf willow is found throughout DNPP in a variety of habitats over a wide elevational range from forest to tundra.
- Plants produce long, relatively straight stems which make good cuttings.
- Plants grow relatively rapidly.
- Cuttings root readily.

Table 5. Rooting ability of several willows (*Salix* sp.) which are common in DNPP.

Species	Rooting ability: Readily along stem	Poor
Salix alaxensis	x	
S. arbusculoides	x	
S. barclayi	x	
S. depressa (= *S. bebbiana*)		x
S. glauca		x
S. pulchra (= *S. planifolia* ssp. *pluchra*)	x	
S. scouleriana		x

Willows produce numerous small seeds which are dispersed for miles by wind, and they will establish naturally from seed on all disturbed sites suitable for willow growth. In other words, where willows grow they will revegetate naturally; where they do not establish themselves, planted cuttings usually won't grow well on a long-term basis. (We have found exceptions to this rule where the surface is inhospitable to willow seedling establishment but the underlying soil is suitable).

We found that nutrients, primarily nitrogen, were the main factors limiting willow growth on placer mine tailings in DNPP (Densmore 1994). We have overcome the nutrient limitations on harsh sites in DNPP by planting cuttings with slow-release fertilizer. Cuttings planted in DNPP with slow-release fertilizer from 1989-92 were still growing well in 1998, but we do not know if the plants will continue to grow well.

Collecting Willow Cuttings

At DNPP, fresh cuttings can usually be planted from the time the ground is thawed enough to dig planting holes until August 21. However, many cuttings planted in August did not sprout until the following growing season, and mortality was higher for late plantings. This was in contrast to our plantings on the North Slope of Alaska, where all fresh cuttings planted after June died (Densmore et al. 1987).

Dormant willow cuttings are often preferred for revegetation because they have higher carbohydrate reserves and can be stored frozen for long periods of time. When freezer space is not available, cuttings can be stored under snow and sawdust. Once the air temperature rises above freezing, the cuttings should be planted as soon as possible because water from the melting snow will thaw the cuttings. Alaskan willows can respire at temperatures close to freezing, using up the carbohydrates stored in the stem. These stored carbohydrates are needed for growth when the cuttings are planted.

We recommend the following:

1. Take advantage of ecotype adaptations, and protect genetic integrity by collecting cuttings near the site to be planted.
2. Cuttings should be about 25-45 cm in length (Fig. 22). Cutting length is limited by two factors. First, the length of the buried portion of the cutting is limited by the size of the planting hole which can be dug efficiently. Second, cuttings produce most of the sprouts within 15 cm of the ground, and the portion of the cutting above this level often dies back.
3. We have usually used cuttings 1.0-2.5 cm in diameter at the base (Fig. 22). Smaller-diameter cuttings lack sufficient carbohydrate reserves. Larger-diameter cuttings are likely to be stem sections more than 5 years old. Cuttings from stem sections over 5 years old are less likely to root because the root initials are buried deep within the wood.
4. Willows in DNPP regularly produce new stems from the base of the plant. Select younger stems which are growing rapidly.
5. Each cutting must have at least one leaf node or bud. The node is the place where shoots originate, and without a node, the cutting will not grow.
6. Do not take too many cuttings from a single plant; instead, spread the impact of the collection throughout the willow patch. Also, since willows are dioecious, selecting cuttings from a number of plants may prevent the cloning of a single sex.
7. Place the cuttings in a plastic bucket along with a few inches of water. Be sure to place the lower end of the cutting in the bottom of the bucket so planters will know which end goes up. Fresh cuttings should be planted soon after collecting, preferably the same day. If a delay is unavoidable, cuttings can be stored for approximately 1 week packed in moist moss, wrapped in plastic, and kept in a cool place.
8. Dormant cuttings can be collected in DNPP from October 15 through April 15. Scout collection sites while identifying leaves persist so that cuttings are taken from the correct species. Collect cuttings as described earlier, pack them in moist moss and/or snow, and wrap them tightly in plastic before storing the cuttings in a freezer.

Planting Willow Cuttings

The following steps for planting willow cuttings should promote establishment and growth:

1. Plant willow cuttings in shallow holes at approximately a 45° angle. The planting hole should be deep enough to bury the cutting and allow 5-8 cm of the cutting to protrude above the soil surface. Leave a shallow watering moat around the cutting.
2. Willow cuttings should be fertilized with a slow-release fertilizer or fertilizer tablets designed for trees and shrubs. We have successfully used Osmocote fertilizer and Agriform fertilizer tablets. The fertilizer should be mixed with the backfill, and the tablets should be placed at the bottom of the planting hole but not touching the cutting.
3. Each planted cutting should be watered with 1 L of plain water or half-strength transplant fertilizer solution.

Expected Results

Willow cuttings root in 1-3 weeks. Growth rates of 0.5 m per year are considered good for areas along the Park Road and in Kantishna. Moose, snowshoe hares, and arctic ground squirrels often browse planted willows.

Autumn Seed Blitz Technique

During the fall, weather conditions become suitable to use seeds to revegetate certain areas with minor effort. The *autumn seed blitz technique* is especially useful for lessening the impacts of social trails and other disturbances related to human trampling. It can also be used on larger disturbances such as construction projects. This technique is quick, easy, and doesn't require any special talents except the ability to recognize a ripe seed and a strong back for raking.

Methods

The autumn seed blitz technique involves harvesting a variety of seeds near the disturbed site and sowing them immediately. The following guidelines should be helpful:

Site Assessment. If a quick site assessment reveals bare ground caused by a lack of propagules and microsites, then use the autumn seed blitz technique. The soil must have the ability to germinate and grow seedlings. Look for soil with a large percentage of silt and clay, and some organics. Throughout the summer, construct a written inventory of disturbed sites that could be revegetated using this method.

Timing. On a cool, dry day in early September, with a crew of four to six workers, travel to each site listed on the revegetation inventory. Windows of opportunity for this type of work can be quite small, so the job must be done quickly and efficiently. The actual work does not take much time.

Collecting Seeds. At each site, collect seeds from a variety of plants. It is not necessary to know what species are collected, only that the seeds are ripe. When collecting in disturbed areas, however, make sure dandelions and other nonnative plant seeds are not included in the mix. During early September most seeds are ready, or past ready and dispersed. Seeds must be dry on the plant. Dry seeds can be coaxed from a seed head or pod, while moist seeds cannot. Species that are disturbance-oriented are especially useful and are found easily along roadsides and streams. Harvest whole seed heads and stalks with scissors or clippers and place them in a large bag. Species can be mixed together in the same bag. One lightly packed grocery sack should cover about 100 m^2.

Seeding the Site. Seed the area to be revegetated by briskly rubbing the seed heads and stalks between your hands and letting the seeds and chaff disperse over the site. Often, the heavy seeds gravitate towards the bottom of the bag. These seeds should be dispersed properly over the site.

Fertilizer. Fertilize the site with a slow-release fertilizer.

Raking. Rake the seeds and fertilizer into the soil. Raking holds the seeds on site and creates conditions that greatly enhance seed germination. On a windy day, it is necessary to rake the site before and after the seeds are sown. Raking before seed dispersal increases the amount of seed that lands and stays on the site. On sites that are well compacted, it may be prudent to break the soil up with a mattock or tractor. A toothed tractor bucket can often be used instead of rear-mounted ripper tines.

Expected Results

By swamping a site with seeds from a variety of native species, we allow site conditions to determine which species will survive. This technique usually provides good cover and high species diversity. The revegetation project on the west side of the Eielson Visitor Center is a successful example of this technique (see Species Tested and/or Used for Native Plant Revegetation section). Typically these sites are vulnerable to human disturbance and must be adequately protected with signs and barriers.

Project Protection Techniques

It takes surprisingly little foot or vehicle traffic to destroy a revegetation site. For this reason, all projects must be protected from further disturbance. This requires finding the middle ground between adequate site protection and overly conspicuous and offensive barriers. Project protection is often a frustrating task because it so often fails. Persistence and patience are essential when visitors trample a revegetation project.

Methods

Signs. Signs should be a part of all project protection tactics. We have used three basic signs to restrict foot and vehicular traffic. These signs include:

1. **"AREA CLOSED - REVEGETATION PROJECT"**
2. **"STAY ON TRAIL - REVEGETATION PROJECT"**
3. **"SENSITIVE AREA - PLEASE KEEP OFF"**

When used, signs should be mounted on standardized sign posts, such as those used for wildlife closures. When posting a sign, it is usually necessary to dig a hole with a mattock, ensuring that the sign stays in the ground.

Signs can be used without barriers, but this has proven only somewhat effective. Interpretive displays describing

the need for revegetation and the fragile nature of the vegetation are also an option and have been used at the Eielson Visitor Center and the Polychrome Comfort Station.

Rope Barriers. Past projects have been barricaded with a single manila rope on 2 ft rebar posts. This method, along with appropriate signs, will work. Unfortunately, rebars can present a hazard to park visitors, and wildlife can be ensnared in the rope. A low rope barrier, perhaps 15 cm above the ground and mounted on wood or fiberglass stakes, may be preferred. If wooden stakes are to be used, they should be made of 2 x 2 in. lumber. We have used 1 x 2 in. lumber, but it cracks easily when hammered. Drill holes through each stake to hold the rope.

Manila rope is a natural fiber and is appropriate for the natural environment; however, its fibers will relax and contract with weather conditions, often leaving the rope lying sloppily on the ground. To remedy this, include several feet of shock cord anywhere along the length of rope. This will keep the rope taut by creating constant tension. This works only if the rope is free to move through holes in the stakes.

Rock Barriers. Large rocks can be used to border a revegetation project. Rocks protect against vehicular intrusion but do little to dissuade foot traffic. If a project needs long-term protection, it may be necessary to include large rocks in the landscape design. These rocks can be partially buried to give the site a more natural appearance.

Vegetation Barriers. Vegetation barriers have been very successful, especially at helping to eliminate social trails. Spruce trees over 1 m high are particularly useful. Once a tree is planted at the head of a revegetated social trail or road, few visitors will venture past. Spruce, willow, and alder have been used to hide sites such as abandoned roads and gravel pits. Hiding a project is often a successful protection technique.

Education. The interpreters at DNPP can assist the revegetation effort by explaining past and ongoing projects. Campfire programs offer a good opportunity to impart information about projects near the campground. Interpreters and drivers on shuttle busses can point out revegetation projects along the road corridor.

Design. It is essential that information about people's travel habits is taken into consideration during the revegetation project design. When pedestrians are provided with sensible travel routes, they generally use them without disturbing the revegetation project.

Mulch. Mulch, though not very effective for growing plants in the subarctic, can be used effectively to send the message that a revegetation project is ongoing. Strips of coconut fiber mat strategically placed can direct traffic towards a less destructive route.

Revegetation Results

Five-Year Results of Seeding a Legume and Grass Mix and Planting Container-Grown Seedlings

We revegetated newly constructed road fill slopes along the first mile of the Park Road. This area is close to tree line, and the species selected for revegetation were plants which naturally revegetate gravelly disturbances in this part of the park. This appendix presents data on the 5-year results of two revegetation methods used on this site. The first method was direct seeding of two native legumes and a native grass. This method was used to speed up the revegetation of important species which usually take 10-20 years to colonize naturally (Fig. 3). These species, like most other subarctic plants, grow slowly from seed. The legumes and grasses provide very little cover during the first year but reach mature size and flower during the third year. The second method was to plant greenhouse propagated containerized seedlings of six showy flowering forbs. The objectives for this method were to immediately improve visual quality while leaving most of the site open for natural revegetation.

Materials and Methods

Denali Park Road construction was completed after snowfall in 1990, and the road fill slopes were revegetated during the following growing season. The legume and grass seed mix was sown 15-22 May 1991. Annual ryegrass was included in this mix to provide temporary erosion control. The composition of and sowing rate for the seed mix was as follows:

Seeds/m^2	
Oxytropis campestris (acid scarified)	50
Hedysarum alpinum	50
wheatgrass	375
(*Agropyron macrourum* [= *Elymus macrourus*])	
(included some *A. violaceum* [= *E. alaskanus*])	
annual ryegrass	175
(*Lolium multiflorum* [= *L. perenne* ssp. *multiflorum*])	

Each species was sown separately, the seeds were raked in, and the area was fertilized with Osmocote (14-14-14 NPK) at 50 g/m^2. Some areas were overseeded on 21 September 1991 with the same native seed mix without the annual ryegrass. Seeds were not raked in or refertilized.

Native plant seedlings were grown at the Alaska State Forest Nursery. Plants were seeded in root trainer containers in March 1990 and 1991, grown in the greenhouse until June, hardened off, and maintained

outdoors until planted. Containerized seedlings started in 1990 were overwintered outside at Denali until planted in 1991. Seedlings were planted 8-12 July 1991, in a random pattern, with an average density of one seedling/m^2. Each seedling was fertilized with 10 g Osmocote (14-14-14 NPK), with 5 g placed in the bottom of the planting hole and 5 g mixed in the backfill.

We evaluated the revegetated areas 20-28 June 1996. We established six 10 m line transects parallel to the roadway and a 10 x 0.5 m plot on the upslope side of each transect. Three transects were in areas seeded with the legume and grass mix and three in areas planted with containerized seedlings. One of the legume and grass transects had been overseeded. We measured the cover of bare soil, moss, cryptogamic crust, litter, and vascular plants by species along each line transect. For each 10 x 0.5 m plot, we listed all the vascular plant taxa which had naturally revegetated from seed, including seed produced by plants we had seeded or planted as containerized seedlings. For forb taxa, we recorded the number of naturally seeded plants.

Results and Discussion

After 5 years, the legume and grass mix produced a vigorous, aesthetically pleasing roadside stand of the two legumes and the wheatgrass (Figs. 4 and 5). Litter, moss, and cryptogamic crust stabilized approximately 60% of the soil surface (Table 6). The annual ryegrass died after one growing season and did not reseed itself. The legumes and wheatgrass were reproducing from seed to fill in gaps in the stand, and the wheatgrass had spread into nearby unvegetated disturbed areas (Table 7). In comparison with unseeded areas, the legume and grass stands substantially reduced natural revegetation by other species (Table 7). The primary benefit was that exotic species were largely excluded, and the exotic dandelions (*Taraxacum officinale*) which managed to establish were not vigorous. The legume and grass stands also had fewer tree and tall shrub seedlings, which may reduce the need for roadside mowing. The ability of the legume and grass stand to inhibit or delay colonization by other species may not be desirable on sites where restoration of the original native plant community is the primary goal.

Table 6. Cover after 5 years for two revegetation methods used on Park Road fill slopes. Methods were seeding with a legume and wheatgrass mix and planting with container-grown seedlings. Values are percentage (mean ± SE, n = 3 transects) cover for bare soil, moss and cryptogamic crust, litter, and vascular plant taxa.

Revegetation Method			
Seed mix		Container-grown seedlings	
Type cover	Percent cover	Type cover	Percent cover
Ground cover		**Ground cover**	
Bare soil	41.7 ± 13.4	Bare soil	83.0 ± 4.6
Moss, cryptogamic crust	6.0 ± 2.6	Moss, cryptogamic crust	2.3 ± 0.9
Litter	51.0 ± 10.8	Litter	11.4 ± 2.4
Native plants		**Native plants**	
Agropyron macrourum	2.7 ± 0.4	*Arnica frigida*	1.8 ± 1.5
(=*Elymus macrourus*)[a]		*Artemisia tilesii*	0.7 ± 0.6
Hedysarum alpinum	9.1 ± 2.1	*Aster sibiricus*	4.9 ± 1.7
Oxytropis campestris	9.0 ± 4.0	*Hedysarum alpinum*	4.4 ± 1.6
All species	20.8 ± 2.3	*Senecio lugens*	0.5 ± 0.4
		Solidago multiradiata	0.2 ± 0.1
		All species	12.5 ± 0.8
Natural revegetation of native plants		**Natural revegetation of native plants**	
All species	0.5 ± 0.3	All species	1.8 ± 1.0
Exotic weeds		**Exotic weeds**	
All species	0.0 ± 0.0	All species	4.0 ± 3.1

[a]Nomenclature follows Hultén (1968); updated nomenclature from U.S. Department of Agriculture, Integrated Taxonomic Information System (http://www.itis.usda.gov) is listed in parentheses.

Most of the container-grown seedlings which had been planted in roadside areas were alive and vigorous after 5 years, and plants were still showy when flowering. *Aster sibiricus* spread vegetatively to produce clumps of plants and provided the most cover (Table 6). Other species were spreading from seed (Table 7). Natural revegetation, however, did not occur as rapidly as expected, and 83% of the soil was still bare after 5 years (Table 6). Furthermore, most of the cover from natural revegetation was exotic weeds.

We recommend seeding gravelly areas close to exotic weed sources with the legume and grass mix to exclude weeds, rather than relying on natural revegetation. A combination of seed mix and planted seedlings will provide the optimal mix.

Table 7. Species composition, frequency, and density of plants regenerating from natural seedfall 5 years after revegetation methods were used on Park Road fill slopes. Density values are mean ± SE, n = 3 transects. Methods were seeding with a legume and wheatgrass mix and planting with container-grown seedlings.

	Seed mix		Container-grown seedlings	
Primary seed source	**Freq.[a]**	**Plants/m²**	**Freq.**	**Plants/m²**
Mature plants from seed mix				
Agropyron macrourum (= *Elymus macrourus*)[c]	3	p[b]	3	p
Hedysarum alpinum	3	6.3 ± 5.7	0	0.0
Oxytropis campestris	3	5.0 ± 3.6	0	0.0
Mature plants planted as seedlings				
Arnica frigida	0	0.0	1	2.3 ± 2.3
Artemisia tilesii	0	0.0	2	5.1 ± 4.8
Aster sibiricus	0	0.0	1	0.1 ± 0.1
Hedysarum alpinum	0	0.0	3	3.1 ± 1.6
Senecio lugens	0	0.0	1	0.2 ± 0.2
Solidago multiradiata	0	0.0	2	1.1 ± 0.9
Colonizing native plants				
Herbs				
Achillea borealis (= *Achillea millefolium*)	2	0.3 ± 0.2	3	5.7 ± 2.4
Agrostis scabra	0	0.0	1	p
Calamagrostis canadensis	0	0.0	1	p
Epilobium angustifolium	0	0.0	2	0.9 ± 0.4
Hordeum jubatum	2	p	3	p
Potentilla norvegica	2	0.3 ± 0.1	3	8.1 ± 7.5
Trees and tall shrubs				
Betula papyrifera	0	0.0	1	0.1 ± 0.1
Picea glauca	1	0.1 ± 0.1	2	1.4 ± 0.5
Populus balsamifera	3	0.3 ± 0.1	3	2.2 ± 0.8
Salix sp.	1	0.1 ± 0.1	2	0.1 ± 0.1
Exotic weeds				
Bromus inermis	0	0.0	2	p
Plantago major	1	0.1 ± 0.1	1	0.3 ± 0.3
Taraxacum officinale	3	0.5 ± 0.3	3	36.6 ± 30.8

[a]Freq. = frequency, the number of transects on which a species occurred.
[b]p = plants present. Individual seedlings were not counted for grasses.
[c]Nomenclature follows Hultén (1968); updated nomenclature from U.S. Department of Agriculture, Integrated Taxonomic Information System (http://www.itis.usda.gov) is listed in parentheses.

Vegetative Change in Transplanted Sod

The Visitor Access Center (VAC) in Denali National Park and Preserve was constructed in 1988 and 1989. The construction design included revegetating the disturbed area around the building and parking lots with transplanted sod. Construction was scheduled so that one large parking lot was not cleared until disturbed areas were ready for revegetation. We participated in design specifications and monitored the contractor who transplanted the sod. We evaluated the transplanted sod around the VAC in 1996.

Materials and Methods

The site where the sod for the VAC was salvaged was open white (*Picea glauca*) and black spruce (*P. mariana*) and quaking aspen (*Populus tremuloides*) forest with a low shrub understory and a ground cover dominated by moss. Small white spruce (0.25-1.0 m tall), quaking aspen suckers suppressed by browsing, and decadent willows (*Salix* sp.) were present in forest openings. The site was burned in a wildfire in 1924, and tall willows had reached the decadent stage with many dead branches.

Sod was salvaged from forest openings and immediately transplanted to the area around the VAC in late July and early August, 1989. The sod was cut with a chainsaw into 0.9 x 0.9 m squares; the organic layer and mineral soil were cut down to a maximum depth of 0.4 m, or to gravel, which was usually less than 0.4 m below the surface. The sod blocks contained everything present in or on the block, including small spruce, suppressed quaking aspen suckers, tree roots, small burned snags, and standing dead willow branches. Topsoil obtained from the overburden from a nearby gravel pit was spread to a depth of 5 cm over the gravel subsoil before sod was placed. Sod blocks were fitted together to completely cover the disturbed area and watered.

We evaluated the transplanted sod in 1996 at the end of the seventh growing season after transplanting. We established two line transects, one 7 m long and one 10 m long, which reached across the transplanted sod from the VAC to the edge of the sod. Each transect on transplanted sod was paired with a line transect in undisturbed sod with vegetation similar to that from which the original sod had been transplanted. We measured the cover of litter, nonvascular plants, and vascular plants by species along each line transect. Each line transect included a 0.5 m-wide plot on one side, which extended the length of the transect. For each of these plots, we recorded the number of fireweed (*Epilobium angustifolium*) stems.

Results and Discussion

After 7 years, the transplanted sod was vigorous and visually attractive but had changed in vegetative composition (Figs. 8 and 23, Table 8). The most conspicuous change was the increase in grasses and forbs, particularly flowering stems of fireweed. Transplanted sod plots had 5.4 ± 1.4 (mean ± SE) fireweed stems per square meter, but fireweed stems were absent from the undisturbed plots and rare in the adjacent undisturbed areas. Fireweed, other forbs, and the grasses which increased cover on the transplanted sod are species which tend to persist at a low level between wildfires, then resprout vigorously following light burns. The overall cover of woody plants in the transplanted sod decreased, but the effect varied among species. The cover of deciduous shrubs, such as dwarf birch (*Betula nana*) and willow remained relatively constant, but the cover of low evergreen shrubs such as labrador tea (*Ledum palustre*) and lingonberry (*Vaccinium vitis-idaea*) decreased. The cover of mosses declined on transplanted sod, and late successional species such as *Sphagnum* sp. were replaced by colonizer mosses such as *Polytrichum* sp. and species more tolerant of warmer, drier sites. The cover of litter increased, due in part to dead moss.

The changes in vegetative composition which occurred on the transplanted sod at the VAC are similar to changes which we have observed on transplanted sod throughout the park. The vegetative changes are analogous to those which occur in similar vegetation in interior Alaska after a wildfire scorches or partially burns

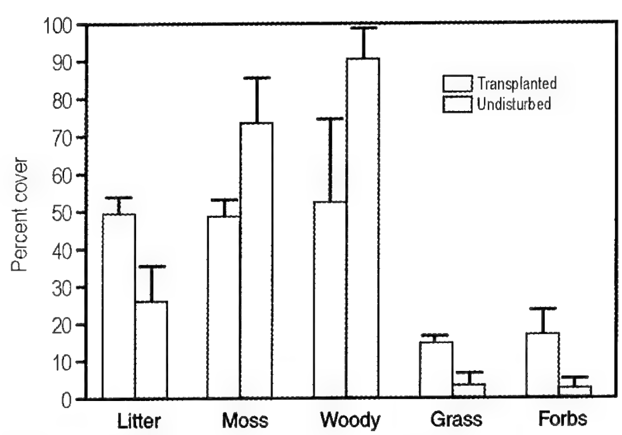

Fig. 23. Percentage cover after 7 years at the Visitor Access Center of mosses and lichens, woody plants, grasses, forbs, and litter on transplanted sod, and on undisturbed sod with vegetation similar to that from which the original sod had been transplanted. Values are mean ± SE, n = 2 transects.

Table 8. Cover on transplanted and undisturbed sod from two vegetation types adjacent to the Visitor Access Center in Denali National Park and Preserve. Values are percentage cover along paired line transects.

	7 m transect		10 m transect	
	Transplant	**Undisturbed**	**Transplant**	**Undisturbed**
Litter	47.0	37.8	52.0	13.8
Mosses and lichens				
Polytrichum sp.	41.5	14.7	15.0	0.0
Sphagnum sp.	0.0	31.1	0.0	0.0
Other mosses	11.5	12.9	29.3	80.0
Lichens	p[a]	3.5	3.7	6.2
Woody plants				
Betula nana	50.5	40.6	0.0	0.0
Empetrum nigrum	6.9	3.1	2.6	9.4
Ledum palustre	5.5	32.2	0.0	25.6
Picea glauca	8.0	p	0.7	p
Populus tremuloides	0.5	0.0	4.4	p
Rosa acicularis	0.0	0.0	3.6	0.0
Salix depressa (= *S. bebbiana*)	3.0	2.8	0.7	1.2
S. pulchra (= *S. planifolia* ssp. *pulchra*)	0.3	p	0.0	p
Vaccinium vitis-idaea	3.0	15.2	12.1	39.4
V. uliginosum	p	7.8	2.9	4.4
Graminoids				
Agrostis scabra	p	0.0	0.0	0.0
Carex sp.	10.3	5.6	2.5	0.0
Calamagrostis canadensis	0.0	0.0	p	0.0
Festuca altaica	1.6	0.0	6.9	1.1
Luzula multiflora	0.2	0.0	p	0.0
Poa sp.	0.9	0.0	6.3	0.0
Forbs				
Epilobium angustifolium	3.8	0.0	24.3	0.0
Aconitum delphiniifolium	0.0	0.0	0.0	p
Anemone parviflora	0.0	0.0	0.0	p
Equisetum pratense	p	0.0	0.0	0.0
Geocaulon lividum	1.0	0.0	0.0	0.0
Lupinus arcticus	0.0	0.0	p	3.8
Mertensia paniculata	p	0.0	0.0	p
Pedicularis labradorica	p	0.0	0.0	0.0
Petasites frigidus	5.0	1.1	0.0	0.0
Polemonium acutiflorum	p	0.0	p	0.0
Stellaria sp.	p	0.0	p	0.0

[a]p = present but less than 1% cover.

the organic layer (Van Cleve et al. 1986). Both burning and transplanting usually increase soil temperature and nutrient availability, and decrease soil moisture.

Species Tested and/or Used for Native Plant Revegetation

Table 9 lists species we tested and/or used for native plant revegetation from 1976 to 1994. The propagation methods we used for these revegetation projects are the same methods described earlier in this document: cuttings = woody plant cuttings planted directly into the soil; rooted cuttings = cuttings rooted in a greenhouse and grown in pots before planting outside; rhizomes = rhizomes excavated and transplanted to the revegetation site; seedlings = plants grown from seed in containers in a greenhouse; seeds = sowing seed directly on revegetation sites; and transplant = excavating individual plants or blocks of sod and planting on revegetation sites. Revegetation locations are shown in Fig. 24. DBC = destroyed by later construction.

Table 9. Species tested and/or used for native plant revegetation in DNPP from 1976 to 1994.

Scientific name[a]	Propagation method	Location[b]	Year planted	Comments and status in 1999
Trees				
Picea glauca	seedlings	16	1992	Planted in regraded placer mine tailings; experienced high mortality and poor growth; best survival and growth where planted under alder
	transplant	2	1976	Vigorous; 4-5 m tall
		3c	1990	Healthy
		3d	1991	Healthy but slow growing; most plants DBC
		3e	1989	Trees root-pruned a year before transplanting died or grew poorly, but unpruned trees dug up individually or with sod squares and immediately replanted are healthy
		6b	1985	Transplanted trees effectively blocked abandoned road, permitting natural revegetation
		8	1988	Healthy; trees effectively blocked off-site camping and allowed natural revegetation
P. mariana	transplant	3e	1989	Healthy
Populus balsamifera	cuttings	12	1976	Few surviving; 2 m tall; surrounded by natural revegetation
		16a	1989	Low survival, but survivors with slow-release fertilizer healthy; 1-2 m
P. tremuloides	transplant	3e	1989	Trees are alive but not vigorous
		3f	1992	Dead or barely alive
Shrubs				
Alnus crispa	seedlings	3f	1991	Vigorous
(= *Alnus viridis* ssp. *crispa*)		16a,b	1989	Vigorous
Betula nana	seedlings	16a	1992	Healthy but growing very slowly
	transplant	3e	1989	Healthy; some plants which initially died back resprouted
		11a,b	1989	Healthy
		14a	1989	Most vigorous, but some plants which lost soil from roots during transplanting died back and did not fully recover
		15	1988	Vigorous
Cornus suecica	transplant	14a	1989	Healthy
Empetrum nigrum	transplant	3e	1989	Healthy
		11a	1989	Healthy
		14a	1989	Healthy
Ledum palustre	transplant	3e	1989	Died back; cover decreased after transplanting
		11a	1989	Healthy
		14a	1989	Healthy, but some plants which lost soil during transplanting died back
Linnaea borealis	transplant	14a	1989	Healthy
Potentilla fruticosa	seedlings	5	1986	Vigorous
(= *Pentaphylloides floribunda*)		10	1986	Vigorous
	rooted cuttings	3b,c,h	1991	Vigorous
		3d	1991	Vigorous until DBC
		6a	1987	Vigorous until DBC
		10	1987	Healthy
		11a	1989	Vigorous
		13	1987	Vigorous
Rosa acicularis	transplant	3e	1989	Healthy
Salix alaxensis	seedlings	10	1986	Died
	cuttings	2	1976	Browsed by moose to snow level for approximately 15 years; now 4-5 m tall
		3f	1991	Healthy
		7	1994	Sprouted vigorously from brush bar and stabilized slope
		10	1987	Barely alive, 20 cm tall; slope too dry for cuttings
		12	1986	Many healthy plants 2-3 m tall but obscured by natural revegetation which grew rapidly once visitor traffic was blocked by plantings
		16a	1989	Healthy on well-drained nutrient-poor placer mine tailings with slow-release fertilizer; died without fertilizer
		16b	1991-92	Vigorous; growth much faster with slow-release fertilizer

Scientific name	Propagation method	Location	Year planted	Comments and status in 1999
Shrubs (continued)				
S. depressa (= *S. bebbiana*)	transplant	3e	1989	Healthy
S. glauca	transplant	11a	1989	Healthy
S. pulchra	transplant	3e	1989	Healthy
(= *S. planifolia* ssp. *pluchra*)		11a,b	1989	Healthy
		14a	1989	Healthy
		15	1988	Healthy
Shepherdia canadensis	seed	16a,b	1993	Good establishment, even under coconut fiber mats; slow growth to 10-20 cm diameter
	seedlings	10	1987	Vigorous; plants 75-120 cm diameter
		16a,b	1993	Slow initial growth; plants 30 cm diameter
Vaccinium uliginosum	transplant	3e	1989	Died back; cover decreased after transplanting
		14a	1989	Healthy, except for some plants which lost soil from roots during transplanting
		15	1988	Healthy
V. vitis-idaea	transplant	3e	1989	Died back; cover decreased after transplanting
		14a	1989	Healthy, except for some plants which lost soil from roots during transplanting
Forbs				
Arnica alpina	seedlings	1	1988	Healthy; plants have produced hundreds of new plants from seed
A. frigida	seed	4	1985	Plants grew slowly even though fertilized with slow-release fertilizer; cover per plant only 10 cm^2 after two years, but healthy until DBC
	seedlings	3a,d	1991	Vigorous with many flowers but many plants DBC
		3c	1991	Vigorous with many flowers, up to 30 cm diameter, but plants by and under entrance sign badly trampled by visitors photographing sign
		3h	1991	Healthy
		6a	1987	Vigorous with many flowers, up to 30 cm diameter, until DBC
		10	1986	Healthy but slow growing
		13	1987	Alive but overgrown by taller vegetation; must be planted in open areas
Artemisia tilesii	seed	13	1992	Seeded with autumn seed blitz method; many healthy plants
	seedlings	1	1988	Few alive; not vigorous
		3a,b	1991	Vigorous
		5	1986	Healthy; reproducing from seed
		10	1986	Variable with healthy and sickly plants
		11a	1989	Vigorous
Aster sibiricus	seed	4	1985	Plants were healthy but grew slowly even though fertilized with slow-release fertilizer; cover per plant only 20 cm^2 after 2 years; DBC
	seedlings	3a,c,h	1991	Vigorous, spreading vegetatively into mats; many plants DBC
		5	1986	Healthy, spreading vegetatively
		6a	1987	Vigorous until DBC
Epilobium angustifolium	seeds	3a	1991	Failed on gravel fill, even with slow-release fertilizer
		3f	1992	Healthy and flowering; seeded into "seed trap" depressions fertilized with slow-release fertilizer and composted dog manure
		14a	1989	Many plants, but poor growth on subsoil
		14b	1989	Many plants but not vigorous growth
	transplant	3e	1989	Very successful; scattered plants in sod spread rapidly and are vigorous
		11a	1989	Vigorous
	rhizomes	3f	1992	Failed
Mertensia paniculata	seed	4	1985	Plants grew very slowly
	seedlings	3c,d	1991	Healthy
		6a	1987	Vigorous until DBC
	transplant	11a	1989	Vigorous
Myosotis alpestris	seedlings	3a,c	1991	Dead; some dug up by visitors
(= *Myosotis asiatica*)		6a	1987	Vigorous until DBC

Scientific name	Propagation method	Location	Year planted	Comments and status in 1999
Forbs (continued)				
Saxifraga tricuspidata	seedlings	10	1987	Vigorous unless planted with fertilized grass seedlings; must be planted in open areas
		11a	1989	Vigorous
Senecio lugens	seed	4	1985	Plants grew very slowly, but healthy until DBC
	seedlings	3a,c,h	1991	Vigorous, but many plants DBC
		6a	1987	Vigorous until DBC
Silene acaulis	seedlings	11a	1989	Dead, probably trampled
		13	1987	One vigorous plant in open area, 30 cm diameter; most of plants overgrown by taller plants; must be planted in open areas
Solidago multiradiata	seed	1	1987	Plants vigorous, spreading from seed
		4	1985	Plants grew very slowly, but healthy until DBC
	seedlings	1	1988	Vigorous
		3a,c,h	1991	Vigorous, some DBC
		6a	1987	Vigorous until DBC
Leguminous forbs				
Astragalus eucosmus	seeds	4	1985	Unhealthy plants
	seedlings	5	1986	Poor growth; died
		6a	1987	Poor growth until DBC
Hedysarum alpinum	seeds	1	1987	Vigorous, spreading from seed
		3a	1991	Vigorous, spreading from seed
		3g	1994	Plants vigorous but sparse relative to seeding rate
		4	1985	Plants grew rapidly, cover per plant 300 cm^2 after 2 years; flowered third year; plants vigorous until DBC
	seedlings	3a	1991	Most seedlings died when overwintered outside in containers; remainder vigorous and spreading from seed
		5	1986	Healthy
		6a	1987	Vigorous until DBC
Lupinus arcticus	seeds	3a-e	1991	Failed to germinate even when scarified; probably needed more scarification
		4	1985	Good germination; coat of each seed nicked with a file before planting. Plants grew rapidly; cover per plant 340 cm^2 after 2 years; flowered third year; plants vigorous until DBC
		6a	1987	Failed to germinate
	seedlings	6a	1987	Seedlings grew poorly in greenhouse even though inoculated with *Lupinus arcticus* nodules; died after planting
Oxytropis campestris	seeds	3a	1991	Vigorous, self-seeding
		3f	1993	Chaff from 1992 seed cleaning contained a surprising number of seeds which established many plants
		3h	1994	Plants vigorous but sparse relative to seeding rate
		4	1985	Plants grew rapidly, cover per plant 300 cm^2 after 2 years; flowered third year; vigorous until DBC
		7	1994	Vigorous
	seedlings	1	1988	Vigorous; spreading from seed
		5	1987	Original plants dying back but spreading from seed
		6a	1987	Vigorous until DBC
O. deflexa	seedlings	5	1987	Grew poorly, died
Grasses				
Agropyron macrourum and *A. violaceum* (= *Elymus macrourus* and *E. alaskanus*)	seeds	1	1987-88	Plants vigorous and spreading from seed
		3a	1991	Vigorous stands
		3f	1993	Chaff from 1992 seed cleaning contained a surprising number of seeds which established many plants
		3g	1994	Stand sparse, but plants healthy
		4	1985	20 plants/m^2 produced 10% cover after 2 years; plants vigorous until DBC
		7	1994	Vigorous stand
		11b	1989	Healthy; sown with mix of species collected on site

Scientific name	Propagation method	Location	Year planted	Comments and status in 1999
Grasses (continued)				
		14a	1989	Seeded on trampled areas with a mix of species collected on site and covered with coconut matting which was reduced after 10 years to plastic netting and nylon string; scattered plants, not vigorous
Arctagrostis latifolia	seeds	3c	1991	Failed
		11b	1989	Healthy; sown with mix of species collected on site
		13	1992	Healthy plants dominant in mixed species stand produced by autumn seed blitz technique
		14a	1989	Sown on trampled areas with a mix of species collected on site; few plants established; not vigorous
Calamagrostis canadensis	seeds	3a	1991	Plants did not establish on gravel fill
		14a	1989	Seeded on trampled areas with a mix of species collected on site; some areas covered with coconut matting; not vigorous
		14b	1989	Initial growth good but declined when yearly fertilization stopped
	transplant	11a,b	1989	Vigorous; increased growth when sod transplanted
		14a	1989	Vigorous; increased growth when sod transplanted
C. purpurascens	seedlings	3d	1991	Vigorous, but most DBC
Elymus innovatus	seedlings	3d	1991	Vigorous and spreading, but many plants DBC
(= *Leymus innovatus*)		10	1987	Vigorous; spreading vegetatively
		13	1987	Healthy and spreading; patches up to 2 m across
Festuca altaica	seeds	4	1985	Slow growing; 130 plants/m^2 produced 8% cover after 2 years; healthy until DBC
		13	1992	Seeded with autumn seed blitz technique; scattered healthy plants
	seedlings	10	1986	Died
F. rubra	seed	10	1986	Did not establish on unstable subsoil
		11b	1989	Vigorous stands; seed collected from site, fertilized with slow release fertilizer, and visitor trampling restricted
		13	1992	Seeded with autumn seed blitz technique; many healthy plants
		14b	1989	Seeded with mix of species collected on site; many plants not vigorous but still stabilizing soil
	seedlings	10	1987	Alive, but cover decreased when fertilizer was used up; roots and litter stabilizing slope even with decreased cover
		11a	1989	Vigorous, forming sod which has stabilized slope
		13	1987	Vigorous and spreading
Phleum commutatum (= *P. alpinum*)	seed	13	1992	Seeded with autumn seed blitz technique, scattered healthy plants
Poa alpina	seed	1	1987-88	Few plants, not vigorous
		3c	1991	Healthy even though trampled by visitors
		4	1985	Slow growing; after 2 years, 50 seedlings/m^2 provided 2% cover, but plants healthy until DBC
	transplant	6a	1987	Sod was grown from seed in nursery bed and was transplanted to create waterbars; effectively controlled erosion until DBC
Trisetum spicatum	seed	11b	1989	Healthy; seeded from mix of species collected on site

[a]Nomenclature follows Hultén (1968); updated nomenclature from U.S. Department of Agriculture Integrated Taxonomic Information System (http://www.itis.usda.gov) is listed in parentheses.

[b]See Fig. 24 for location of vegetation sites. (1) Parks Highway, mile 231; test plots by DNPP south entrance sign. (2) Parks Highway, mile 232.6, old road. (3) Park Road, mile 0-1.6., (a) roadsides, mile 0-1.2, (b) cut slopes, mile 0-1.2, (c) area around DNPP main entrance sign, mile 0.1, (d) abandoned road to Riley Creek Campground and along road to dump station, (e) Visitor Access Center, (f) abandoned parking lot on both sides of airport access road, (g) cut slopes around airplane parking area on airstrip, and (h) access trail between hotel and train station. (4) DNPP Headquarters. (5) Test plots on gravel fill, mile 5. (6) (a) Savage Cabin gravel pad and trail and (b) Savage Campground, abandoned road. (7) Road cut and fill slopes, mile 20. (8) Sanctuary Campground. (9) Teklanika Campground. (10) Road cut slopes in Sable Pass, mile 42.5. (11) Polychrome Comfort Station, (a) cut slopes behind buildings and (b) trampled areas above buildings. (12) Abandoned Toklat Campground. (13) Eielson Visitor Center. (14) Wonder Lake Campground, (a) abandoned campsites and (b) sod roofs on buildings. (15) Wonder Lake Ranger Station, leach field. (16) Glen Creek, placer-mined watershed, (a) regraded placer mine tailings above the active floodplain and (b) placer mine tailings regraded to construct new floodplains.

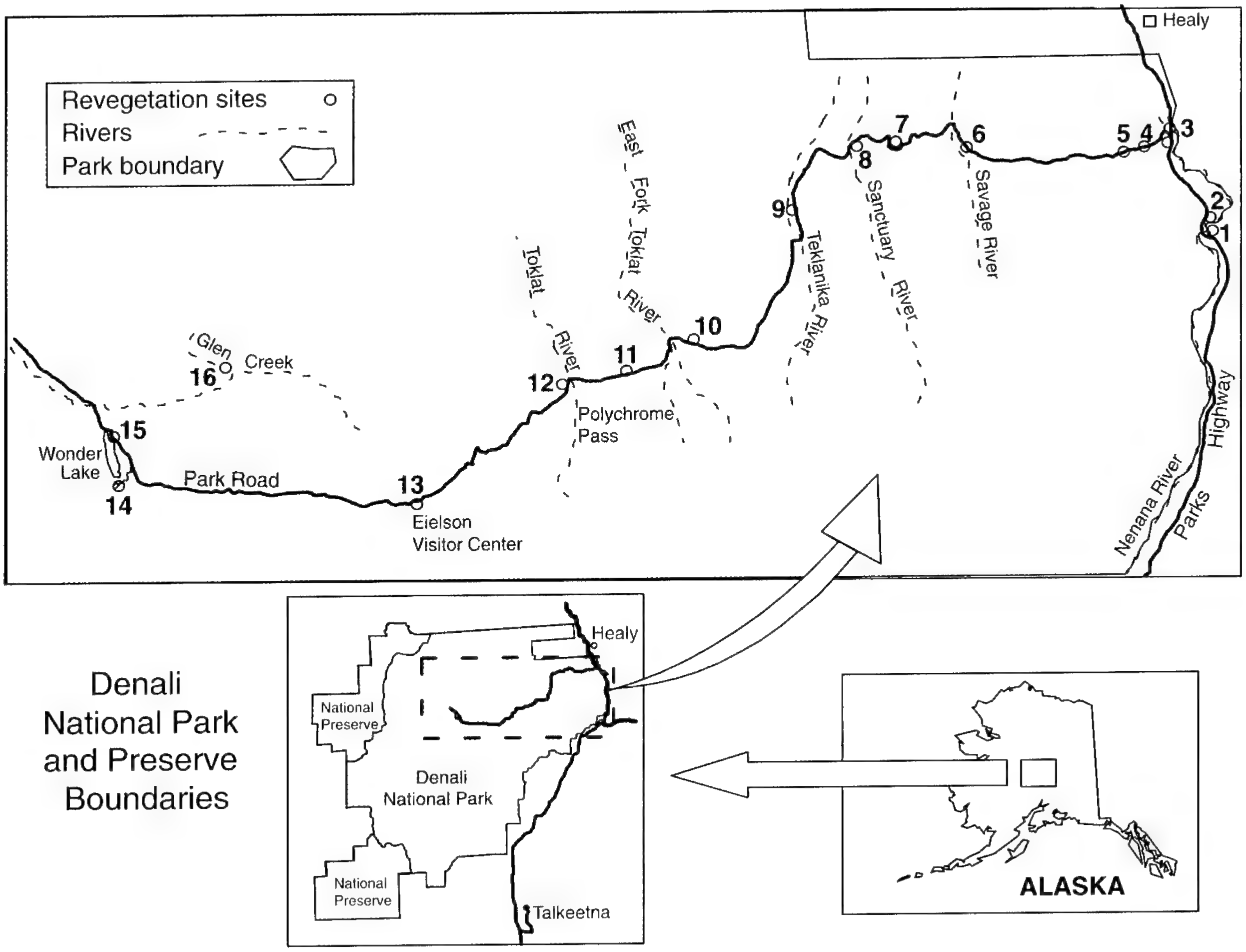

Fig. 24. Location of revegetation sites. Numbers refer to sites mentioned in Table 9.

Acknowledgments

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Glossary

Abiotic - Devoid of life; nonliving.

Annual - Having a yearly periodicity; living for 1 year.

Biotic - Pertaining to life or living organisms; caused or produced by, or comprising living organisms.

Chaff - The dried plant material separated from the seeds.

Community - Any group of organisms belonging to a number of different species that co-occur in the same habitat or area and interact through tropic and spatial relationships; typically characterized by reference to one or more dominant species.

Contour - (1) The outline of a figure, mass, land, etc. (2) Characterized by the making of furrows along the natural contour lines so as to avoid erosion, as on a hillside.

Cotyledon - The first leaves produced by the embryo of a plant.

Cover - (1) Plant material, living (vegetative cover) and dead (litter cover), on the soil surface. (2) The area of ground covered by vegetation of a particular plant species, expressed as a scale (Braun-Banquet scale, Domin scale) or as a percentage.

Dicotyledon - A flowering plant with two seed leaves or cotyledons.

Dioecious - Characteristic of plants or plant species that have male and female reproductive organs on separate individuals.

Ericaceous - Belonging to the family Ericaceae, the heath family.

Exotic - Not native; alien; foreign; an organism or species that has been introduced into an area.

Forb - Any nonwoody plant having broad leaves; a nongrass species.

Graminoid - Of or relating to grasses.

Inoculation - The introduction of a microorganism into a host organism.

Invading - The movement or encroachment of organisms from one area into another.

Legume - Plants of the family Leguminosae (peas, beans, etc.) having fruit that is a dry pod splitting along two sutures: most legumes are nitrogen-fixing.

Litter - A surface layer of decaying detritus covering the ground.

Microclimate - The climate of the immediate surroundings or habitat.

Mycorrhizal - The association between a fungus and root system of a plant.

Native - Indigenous; living naturally within a given area; used of a plant species that occurs at least partly in natural habitats and is consistently associated with certain other species in these habitats.

Nitrogen fixation - The reduction of gaseous nitrogen to ammonia or other inorganic or organic compound by microorganisms.

Nodule - A small knot or joint on a stem or root, especially one containing nitrogen-fixing bacteria.

Parent material - The underlying bedrock or unconsolidated deposits from which soil is derived.

Pathogens - Any microorganism or virus that can cause a disease.

Pioneer - The first species or community to colonize or recolonize a barren or disturbed area, thereby commencing a new ecological succession.

Propagate - (1) Vegetative increase. (2) Sexual or asexual multiplication.

Propagule - (1) Any part of an organism, produced sexually or asexually, that is capable of giving rise to a new individual. (2) The minimum number of individuals of a species required for colonization of a new or isolated habitat.

Rebar - Steel bars usually used to reinforce concrete.

Rhizome - A creeping stem lying usually horizontally at or under the surface of the soil and differing from a root in having scale leaves, bearing leaves or aerial shoots near its tips, and producing roots from its undersurface.

Runoff - That part of precipitation that is not held in the soil but drains freely away.

Salvage - The saving, storage, and use of plant material which would otherwise be lost to disturbance.

Seed coat - The outer layer of the seed.

Turgor - The swollen condition of a cell caused by internal water pressure.

Viable - Having the capacity to live, grow, germinate, or develop.

Waterbars - A transverse levee designed to reduce erosion by slowing and diverting water flow.

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This manual describes methods to revegetate subarctic sites with native plants. The information is based on 20 years of research and revegetation projects in Denali National Park and Preserve and other Alaskan sites. The manual summarizes information about subarctic ecosystems and discusses using this information to evaluate disturbed sites and plan revegetation projects. Revegetation techniques addressed include promoting natural revegetation, legume and wheatgrass seeding, plant salvage and transplant, bioengineering, container-grown plants, alder seedlings, and willow cuttings. The appendixes present long-term data for two specific vegetation projects and for each of the 46 native plant species that have been tested or used for revegetation.

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